1½ hr. mending



# CAPE OF GOOD HOPE.

## DEPARTMENT OF AGRICULTURE.

# TWELFTH ANNUAL REPORT OF THE GEOLOGICAL COMMISSION. 1907.

*Presented to both Houses of Parliament by Command of His Excellency the Governor, 1908.*

CAPE TOWN:
CAPE TIMES LIMITED, GOVERNMENT PRINTERS.
1908.

[G. 17—1908.]
£83-14-8

B.106.1300.08.
C.T.Ltd.—B137.

# Twelfth Annual Report of the Geological Commission, 1907.

## CONTENTS.



---

# Geological Commission of the Colony of the Cape of Good Hope, 1907.

Cape Town,
31st March, 1908.

The Honourable
The MINISTER FOR AGRICULTURE.

SIR,—I have the honour to forward the report of the proceedings of the Geological Commission for the year 1907.

Good solid progress has been made in the scientific mapping of an hitherto untouched part of South Africa, work which has been carried on at the cost of no small hardship and discomfort to the members of the Staff, who have displayed a zeal in the pursuit of knowledge in a country hitherto only known to the trek-boer and the policeman, which is beyond all praise.

In view of the financial position the work of the Commission has been carried on with due regard to economy.

I have the honour to be,
Sir,
Your obedient Servant,

JOHN X. MERRIMAN,
Chairman.

# GEOLOGICAL SURVEY

OF THE

# COLONY OF THE CAPE OF GOOD HOPE.

## DIRECTOR'S REPORT FOR THE YEAR 1907.

During the past year the work of the survey has been carried on in the country north of the Orange River and also in the Divisions of Hope Town, Britstown, and Prieska, south of the River.

I was in the field for six months, completing the survey of parts of Kuruman and Vryburg, and making a journey through Gordonia. Gordonia is chiefly covered with sand, but it is of considerable importance to know the nature of the limited number of outcrops between the German border and the Langeberg–Korannaberg ranges. Much of the Gordonia district is a difficult country to travel in on account of the scarcity of water and the heavy sand; but it was my fortune to make the acquaintance of the Messrs. Lannam, of Mount Temple, Kuruman, who helped the survey very greatly. Mr. Thomas Lanham came with me for some seven weeks through the worst part of the country and gave me the use of several oxen during that period and at other times. Owing to this help I was able to travel further and to get together much more information than would have been possible otherwise. Mr. Lanham has a very good knowledge of the country, and he spared himself no trouble in taking me to spots where he knew of outcrops. The season was a favourable one for travelling, and in spite of the large areas left untraversed the geological structure of the Gordonia Division, except the south-western corner which was left for a future journey, has been to a large extent made out. The chief results are the finding of a great extension of the Karroo beds over Gordonia, the existence of a

wide area of sedimentary rocks, probably continuous with the uppermost group of pre-Karroo sandstones and shales of the central Namaqualand plateaux, and the intrusive relation of the granite of Upington, etc., to the Kheis series. The character of three groups of rocks in the district and their distance from hitherto surveyed parts of the Colony leave doubt as to their relationship, and they have been given new names in consequence, but they may soon be definitely correlated with other beds in Bechuanaland and Griqualand West.

From September to the end of the year I was absent on leave, and had the honour of representing the Cape Survey at the Centenary Meeting of the Geological Society of London, which was held during the last week of September.

Mr. du Toit worked for three months in the west of Mafeking and Vryburg, by arrangement with the Public Works Department, with a view to giving advice as to the position of sites for water boring. The Public Works Department paid the expenses of this survey. He mapped a large area, which, however, largely consists of sand. His discovery of volcanic rocks belonging to the Kraaipan formation is of great interest and will probably be the means of correlating that group with beds in Gordonia, Kenhardt, and Prieska. He also obtained much information about the superficial quartzites, limestones and sands, which, together with my observations further west, throw more light on some difficult questions concerning the remarkable surface deposits of the interior of South Africa. Mr. du Toit also spent three months between Griquatown, Prieska and De Aar. His work included the examination of the southern extremity of the Kaap Plateau, a feature now proved to be to a great extent of post-Karroo age, and the survey of several inliers of volcanic rocks within the Dwyka area of Hope Town and Prieska, which has made clear the relationship of the several volcanic rocks there to the better known occurrences from Kimberley northwards to Bechuanaland.

We owe to the kindness of the Chief Engineer of

the Public Works Department the loan of some instruments which have been of much use in the field during the past year.

Sheet 45 of the Geological map has been issued during the year, and sheet 46 was prepared and printed. Sheets 42 and 52 are in the printer's hands. Two more, 49 and 50 are now being prepared.

Mr. Henry Woods' memoir on the Pondoland Cretaceous Mollusca was issued early in the year. Dr. F. L. Kitchin's work on the Uitenhage Mollusca is finished and is now in the printer's hands. Dr. B. N. Peach, F.R.S., has undertaken to examine the Crustaceans from the Karroo formation.

The following papers written by the staff were published during the year.:—

The Glacial beds in the Griquatown Series, by A. W. Rogers in Report of the S.A.A.A.S. for 1906.

Pipe-Amygdaloids, by A. L. du Toit, Geol. Mag. 1907.

ARTHUR W. ROGERS.

# GEOLOGICAL COMMISSION.

## General Abstracts of Receipts and Disbursements for the Year ended 30th June, 1907.

| Receipts | £ | s. | d. |
|---|---|---|---|
| To Balance 1st July, 1906 ... ... ... ... | 195 | 16 | 3 |
| ,, Government Grant ... ... ... ... | 2,000 | 0 | 0 |
| ,, Refund of overpayment to Agricultural Department | 0 | 10 | 0 |
| ,, Advances (Current), repaid by vouchers ... ... | 290 | 0 | 0 |
| ,, Balances as per Cash Book ... ... ... | 4 | 17 | 6 |
| | £2,491 | 3 | 9 |

| Disbursements | £ | s. | d. | £ | s. | d. |
|---|---|---|---|---|---|---|
| By Salaries ... ... ... ... | 1,000 | 0 | 0 | | | |
| ,, Allowances, Personal ... ... | 304 | 17 | 6 | | | |
| ,, do. Horse ... ... ... | 17 | 5 | 0 | | | |
| ,, Transport ... ... ... ... | 122 | 19 | 2 | | | |
| ,, Postages ... ... ... ... | 22 | 5 | 8 | | | |
| ,, Printing, Books and Magazines ... | 17 | 15 | 8 | | | |
| ,, Analysis ... ... ... ... | 5 | 12 | 0 | | | |
| ,, Rock Sections ... ... ... | 8 | 13 | 4 | | | |
| ,, Horse Purchase Loss ... ... | 8 | 7 | 6 | | | |
| ,, Boys' Wages ... ... ... | 48 | 18 | 0 | | | |
| ,, do. Food ... ... ... | 40 | 6 | 7 | | | |
| ,, Purchase of Oxen and Donkeys ... | 183 | 0 | 0 | | | |
| ,, do. Wagon ... ... | 88 | 2 | 0 | | | |
| ,, do. Scientific Instruments ... | 6 | 10 | 0 | | | |
| ,, Printing of large Scale Maps ... | 151 | 2 | 6 | | | |
| ,, Equipment and Maintenance ... | 56 | 8 | 8 | | | |
| ,, Description of Specimens ... ... | 113 | 1 | 6 | | | |
| ,, Miscellaneous ... ... ... | 5 | 18 | 8 | | | |
| | | | | 2,201 | 3 | 9 |
| ,, Advances made ... ... ... ... | | | | 290 | 0 | 0 |
| | | | | £2,491 | 3 | 9 |

I certify that the above Account has been examined under my directions and is correct, and that the balance agrees with that shown in the Bank Pass Book.

(Signed) W. A. R.

Audit Office, Cape Town, 18th September, 1907.

(Signed) WALTER E. GURNEY,
Controller and Auditor-General.

THEODORE MACKENZIE, Secretary.

# GEOLOGICAL SURVEY OF PARTS OF VRYBURG, KURUMAN, HAY, AND GORDONIA.

By A. W. ROGERS.

# GEOLOGICAL SURVEY

## OF PARTS OF

# VRYBURG, KURUMAN, HAY, AND GORDONIA

---

BY A. W. ROGERS.

---

## INTRODUCTION.

The country described in the following pages extends from near Vryburg through the Motiton, Genesa, and Morokwen Reserves to the Molopo at Kuis, and thence southwards to the Orange River and westwards to the German border. It includes the northern part of the Kaap Plateau and the Kuruman range, the Korannabergen, some of the mountains in Gordonia, the valley of the Orange River between Kheis and Upington and that of the Molopo (often known in that part as the Hygap) between the confluence of the Nossob and Ghous. The Molopo between Kuis and the Nossob was not visited, and a very large area, said to be entirely covered with red sand, lying between the Inkruip and Malanie hills on the east and the Hygap on the west, was not traversed.

The district is characterised chiefly by its general covering of sand and the scarcity of water, and it is the southernmost part of the somewhat ill-defined area called the Kalahari. In local usage the term Kalahari is applied to the country between the Langeberg-Korannaberg ranges on the east and the Nossob-Hygap valley on the west, but the eastern limit north of Korannaberg would seem to be difficult to define; there is no appreciable change in the nature of the country till the Heuning Vley hills are reached, and the area between the Korannaberg and the Kuruman range is of the same character as that north of it. The change from sand-veld to hard ground in that region takes place near Gamagara.[1]

Towards the south the sand-veld extends to the Orange River in many places, but between the tongues of sand which reach the river there are stretches of hard ground, extending in places six or eight miles from the river. On the west, near the Ger-

---

[1] According to the usage adopted by Dr. Passarge in "Die Kalahari," the name is applied to the predominantly sandy country south of the Congo—Zambesi watershed.

man border, the sand-veld becomes broken up by wide tracts of hard ground.

In the eastern and central parts of the district the rocks only crop out in the hills and a few valleys, but in the extreme west and south they are often visible over wide stretches of flat ground.

This district is one of little topographical relief; the surface slopes generally towards the south-west and south, where the Orange River runs at a level of about 2,300 feet above the sea. The highest points are on the Langeberg (6,011), Korannaberg (about 5,800), and the mountains of Gordonia, but the highest part of the district is the north-eastern corner, the northern portion of the Kaap Plateau. The surface slopes very gradually towards the Hygap and Orange Rivers.

The hill ranges are the Kuruman-Heuning Vley ranges (the direct continuation of the Asbestos hills of Griqualand West), the Langeberg-Korannaberg range, the mountains of Gordonia called Scheurberg, Inkruip, Kamkuip, Karreeboomberg, and a few other smaller hills, and the small irregularly-shaped and usually dolerite-capped hills near the German border.

The rivers all join the Molopo and Orange River. Their courses are often very slightly defined; at places they may be crossed without being noticed by the traveller. The Molopo near Kuis, however, has a cañon-like valley over 100 feet deep, and the same is the case with the Hygap for some 15 miles near Zwart Modder. There is seldom running water in these river beds; during my journey there were pools in the Kuruman River at Gasese, in the Mashowing at Madebing, and a large pool in the Molopo at Zwart Modder.

From inquiries made it appears that water has not run continuously from Kuis on the Molopo down to the Orange River within the memory of living man. That part of the Hygap below the farm Bloemfontein carries water to the Orange River after heavy local rain, but it receives no supply from above Abiam. When the Kuruman River, Nossob, or the Molopo "come down" the water does not pass Abiquas Puts; it is there turned out of the old course by drift sand and diverted westwards to the flat ground on Abiquas Puts. The exceptionally heavy rains of 1894 made the Kuruman River flow, and it was from this source that a large area on Abiquas Puts was flooded. The accumulations of drift wood then carried down by the Kuruman River are still to be seen below Lower Dikgathlon. On that occasion the Molopo and Nossob apparently did not add any water to that which flowed down the Kuruman River.

There are no laagtes (dry valleys) entering the Kuruman River below the confluence of the Mashowing, nor are there any joining the Molopo along that part of the valley near Kuis examined by me. The short kloofs on the Molopo between Kolingkwane and Kuis soon attain the general level of the country between the Molopo and the Kuruman River.

The Kuruman River is joined by the Mashowing at Lower Dikgathlon,[1] and the Mashowing is joined by the Kgogole Laagte at Madebing. North of the Kgogole all the laagtes lead directly to the Molopo; the chief of these are the Matamatobo, which the Pepani laagte joins south of Morokwen, and the Genesa laagte, which receives some smaller ones, the Mofanie, Thlakgaming, and others.

The geological structure of the area is simple in the west and north-west, but it becomes complicated in the central part, which is unfortunately the area where the rocks are most completely hidden under sand. Along the extreme southern edge, however, the rocks are exposed; and from the structure of that strip of country and the mountains in the Kalahari it is obvious that the more ancient sedimentary beds have been greatly disturbed, and that igneous rocks have played an important part in the making of Gordonia. It is not only the superficial deposits of more or less recent date, such as the Kalahari sand, that cover the more ancient rocks, but there certainly is a very extensive, though comparatively thin, layer of beds belonging to the Karroo formation in this area. These Karroo rocks are first met with about 15 miles north of Upington, and are widely exposed between the Hygap, which has cut through them below the confluence of the Molopo and Nossob, and the German border (long. 20° E.). That they underlie some of the sand-veld between the Hygap and the Korannaberg is proved by the fact that in the four wells in that region from which rocks other than superficial deposits have been obtained, viz., those at Norokei, Eenzamheid, Witdraai, and Matlapanin, the Dwyka series is met with. The specimens from the two first-named localities were obtained by Dr. Eric Nobbs during a journey made by him on behalf of the Agricultural Department in 1903,[2] and they were brought by him to the office of the Geological Commission; they were the first known evidence of a large outlier of Karroo rocks north of the Orange River and west of Griqualand West. Owing to the determination of these specimens and the special circumstances of my last journey, I left those two wells unvisited, but the southern edge of the area covered by the Karroo formation was found, and the country west of the wells was traversed. The Witdraai and Matlapanin wells gave the only information on the "solid" geology got between the Hygap and a line drawn between Kuis and the Kuie rocks. The Karroo rocks are seen to fill ancient north-south valleys in the Matsap beds between Kuis and Kolingkwani, and they extend into the Bechuanaland Pro-

[1] Both the Mashowing and Kgogole laagtes are wrongly marked as leading north-westwards to the Molopo in all atlases looked into, even in Stieler's Hand-Atlas, 1907 edition. Their true courses are indicated on the Divisional Map published by the Surveyor-General.

[2] E. A. Nobbs, Parl. Reports, C.G.H., G. 39, 1904, Cape Town.

tectorate. They also stretch westwards across the German border. This evidence from so large an area, though obtained at so few places, undoubtedly indicates the presence of a very large outlying mass of the Karroo formation, and we are still ignorant of its western, northern, and eastern limits; it may well cover 10,000 square miles in Gordonia. These Karroo rocks lie flat upon an undulating and in places deeply eroded surface of older rock; they were not met with below an altitude of about 2,700 feet above sea level.

The oldest sedimentary beds seen belong to the Kheis group; they are chiefly mica schists and quartz schists, and they have been invaded by granite. These Kheis beds are separated by a great stretch of newer rocks from undoubted Kraaipan beds, which are the oldest sedimentary rocks known in the north-eastern part of the area; according to Mr. Du Toit's work, the Kraaipan beds have not been shown to be older than the Bechuanaland granite, and my recent observations do not invalidate that statement. There is no direct connection, traceable at the surface, between the Bechuanaland and Gordonia granites. Though correlation with the Kraaipan beds cannot be proved at present, there are beds along the Orange River below Kheis which may belong to the Kraaipan series. These beds are of sedimentary and volcanic origin, and are described below under the name of the Wilgenhout's Drift series. Like the Kraaipan formation, this group has not been found to be invaded by granite.

The Vaal River (Ventersdorp) System is represented by a few detached masses of rock in the north-eastern part of the area, and possibly by some rocks, described below under the name of Koras Series, which occur along the Orange River above Upington.

Rocks belonging to the Transvaal System form a great westerly dipping mass in the north-east of the district. The lowest group of these rocks, the Black Reef Series, makes an escarpment from Motiton down the south side of the Mashowing valley to Garaphoane, where it turns northwards and trends N.N.E. through the Morokwen Reserve; the Campbell Rand group follows to the west, and the area occupied by it is the north end of the Kaap Plateau. The Lower Griqua Town beds form the Kuruman-Heuning Vley-Skelek range, the continuation of the Asbestos Mountains of Griqualand West; they are followed westwards by the Middle Griqua Town beds, which are rarely exposed. There is uncertainty as to the manner in which the Transvaal formation comes to an end on the eastern side of the southern Kalahari; the angle of dip becomes higher towards the Langeberg-Korannaberg range, and within the Korannaberg highly-inclined beds belonging to the Transvaal System are exposed along the axes of overturned anticlines of the Matsap Series, but west of that range there have been found only Kheis, Matsap, Dwyka, and other rocks which cannot yet

be identified with any member of the Transvaal System; whether one of these other groups may partly represent that system will be discussed later.

The Matsap beds form the Langeberg-Korannaberg range, which makes a wide curve round the south-eastern Kalahari, and some of the mountains within it; they cross the Molopo into the Protectorate between Kuis and Kolingkwane, but they have not been recognised west of the Karreeboom Laagte hills.

The extreme western part of the district north of Ghous is characterised by the presence of almost horizontally-lying sandstones, quartzites, and shales, which rest unconformably upon granite and schists, and are unconformably overlain by the Dwyka Series. This group of arenaceous rocks, here called the Zwart Modder Series, has not yet been correlated with any other group in the Colony, but it is certainly a very important element in the geology not only of Gordonia, but of the eastern part of German South-west Africa. It extends from Ghous on the Hygap past Rietfontein and westwards across the German border. Excepting the anticlinal fold near Sannah's Poort, no considerable disturbances have been noted in these beds.

The recent and sub-recent deposits are of great importance in this district. They include sand and various rocks formed by cementation of sand by calcium carbonate and silica, and rocks chiefly composed of calcium carbonate or of silica.

## The Kheis Series.

In the Annual Report for 1899[1] some quartz schists and associated rocks were described from the Prieska division under the name of Kheis beds, because they appeared to be continuous with the rocks in the Kheis area north of the Orange River, marked on Stow's map.[2] This year's work has shown that the schists at Kheis are just like those of Brakbosch Poort hills in Prieska, and there can be no doubt that the rocks in the two areas belong to one series and are in continuity beneath the Orange River. A previous year's work[3] showed that the supposition of Stow that the schists of Kheis are represented by some rocks in the Campbell Rand escarpment at Leijfontein was an error. The Kheis beds have not yet been identified west of Hay, Kuruman, Gordonia, and Prieska.

The rocks included in this series are chiefly quartz-schists and quartzites; by the increase of the proportion of mica they become mica-schists. There are also some gritty rocks and magnetite and other schists.

---

[1] Ann. Rep. Geol. Comm. for 1899, pp. 73—76.
[2] Quart. Journ. Geol. Soc., vol. XXIX., 1873, pl. XXXV.
[3] Ann. Rep. Geol. Comm., for 1905, p. 153, and Trans. Geol. Soc., S.A., vol. IX., p. 1 and pl. II. Stow., *loc. cit.*, p. 660.

The series crops out along the Orange River below Buchu Berg, and appears at the surface for some 34 miles down the river as far as the farms Sterkstroom and Groot Drink. It re-appears on Koras, and stretches thence to Upington Common. It probably underlies a great area north of the river near Kheis, but in that country the rocks are only seen at Scheurberg, England, the Gamotep, and Kuie ridges, and in a few other small hills; north of Sand Kuie they are almost entirely hidden under the sand within the Colony, so the northern limit of the Kheis beds is unknown.

The nature of the junction with the Matsap beds of Buchu Berg, which is geologically a part of the Langebergen, has not yet been determined.

The quartz-schists make low outcrops on Zaal Werf and Tsebe, and on Tsebe there is a brownish-grey gritty rock interbedded with them. This gritty rock is well bedded, and there are several bands of it, the thickest being 30 feet and 100 feet thick respectively; these two occur on the sides of thick dykes of dolerite of the Karroo type, but the thinner bands, some of which are lenticular and thin out when followed along the strike, are quite independent of the dykes. In hand specimens the grits have a strong resemblance to rocks belonging to the Malmesbury series in the Cape and other South-western Divisions. A thin section (1761) cut from one of the large bands of rock is seen under the miscroscope to be made up chiefly of grains of quartz and a turbid substance, which have a distinct parallel arrangement. The quartz areas are clear, but contain a few dusty inclusions and very small flakes of mica; they interlock completely after the manner of the quartz in quartz-schist, and the boundaries of originally detrital grains are not visible, though from the appearance of the rock to the unaided eye one would expect to see such grains under the microscope. The cloudy material is a biaxial mineral, and has the appearance of felspar considerably decomposed; it contains very minute flakes of sericite and much brownish dusty matter. There are also epidote and small crystals of magnetite, evidently developed in place. The only other determinable minerals are sericite and calcite, which are present in small quantity only.

Thin layers of magnetite-schist, which is merely quartz-schist very rich in magnetite, occur on Kheis, but neither here nor elsewhere in Gordonia do such magnetic rocks form a considerable part of the Kheis series, as they do of the Kraaipan group of Bechuanaland and of certain masses of rock within the Prieska granite area formerly supposed to be detached portions of the Griqua Town series.

Some green schists associated with the Kheis beds along the Orange River are found on microscopic examination to be so like rocks that were taken from what were evidently intrusive dykes that they will be described with these on a later page.

The strike and dip of the Kheis beds below Buchu Berg vary

greatly, and it was impossible to trace out the stratigraphical succession of different bands of more or less micaceous rock. On Zaal Werf, Tsebe, Brand Boom, and Kheis the strike changes from E. 20° S. to N. 10° E., but does not appear to turn west of north; below Kheis a north-westerly direction predominates between Spitzkop and Sand Draai, and towards Sterkstroom the strike turns more and more towards E.N.E., parallel to the limit of the series on Sterkstroom and Groot Drink. This boundary line is a fault, for on the north-western side not only are the rocks and their structure quite different, but such that there cannot be an unconformity along the line. Near the river a large mass of intrusive diabase (see p. 86) separates the Kheis rocks from the group described below under the name of Wilgenhout's Drift Series, but about 2½ miles from the river bank one passes abruptly from the Kheis beds with E.N.E. strike on to well-bedded quartzites with bands of mica-schist, which have a steady dip towards E.N.E., and form a series of parallel hill ranges with the same strike as far out as the Karreeboom Laagte hills. The uniform strike of these rocks and their distinct bedding throughout the parts seen separate them sharply from the Kheis beds, though portions of each in hand specimens have considerable lithological similarity; they cannot be traced continuously into rocks whose age is known, for they are isolated on the north and east by the Kalahari sand. I was in doubt as to their relationship when amongst them, and further work in the district did not wholly remove the difficulty, but owing to their parallelism of strike with the Matsap beds of the ranges further east and a considerable lithological resemblance to the Lower Matsap group of the eastern foothills of the Langebergen (including the presence of a band of conglomerate at the base), they will be placed in the Matsap series in this report.

On Rooi Sand some hills trending N. 40° E. rise from the area of Kheis beds at a distance of 2½ miles from the river, and are continued as the Tities Poort range. They consist of quartzites and quartz-schists, which certainly belong to the Kheis series. The north-eastern part of the range has not yet been examined, but especial interest is attached to it because it must somewhere meet the western group of mountains on the farm Scheurberg, which at least at their northern end are made entirely of Matsap beds. Whilst the Tities Poort range on Rooi Sand trends about north-east, the western range on Scheurberg has a north-north-westerly course.

There are at least five small hills formed by the Kheis quartzites and schists on Tities Poort and O Poort; the strike of the southernmost of these rocks is N.N.E., but on O Poort they turn to a few degrees west of north.

The Kheis beds in this area are traversed by numerous dykes of amphibolites and dolerites (see pp. 82-85), by three masses of granite (see p. 22) and by two kinds of quartz veins. The

older quartz veins are of pinkish and white granular or sugary quartz, and they do not appear to contain sulphides; the later veins are of ordinary quartz, containing both iron and copper sulphides, which at places have given rise to red and green stained outcrops.

The mountain called Scheurberg on the farm of the same name is made entirely of the Kheis beds. It is by far the most rugged range in Cape Colony north of the Orange River, though it is not so high as many parts of the mountains formed by the Matsap and Griqua Town series. The length of the range is only six miles; the highest point, where a beacon of the Geodetic Survey stands, is 4,317 feet above sea level,[1] but only 880 feet (by anaeroid) above the flat sandy ground near England, five miles to the north-east. The rugged surface is due to the action of the weather on the alternating harder and softer bands of quartzite, quartz-schist, and mica-schist which make the mountain. The Matsap and Griqua Town series are more uniformly resistant to the weather, and therefore give rise to less jagged ridges.

By far the greater part of Scheurberg is made of quartz-schist; pure quartzites are seldom seen; rocks which look like quartzites on the outcrop present a freshly broken surface covered with very minute flakes of mica. Those rocks which contain rather more mica break up under the influence of the weather into long, but thin slabs. Magnetite occurs in thin bands on the eastern side of the mountains, and these bands, which presumably coincide with the bedding planes, are often highly contorted. The strike throughout the mountain is N. 20° W., and the dip may be in either direction. The planes of schistosity have the same strike as the beds, but their dip is more regular, though they have a sharply anticlinal arrangement, for they dip in an easterly direction on the east side of the mountain and westwards in the central and western parts.

The quartz veins seen were all of the sugary type mentioned in connection with the Kheis beds. They are frequently broken and separated into more or less lenticular streaks parallel to the schistose planes of the enclosing rock.

About five miles north-east of Scheurberg beacon there are two low outcrops of the Kheis beds at the place called England. The largest outcrop is only 100 yards long, and rises to a height of 8 feet above the sand. The rock is a fine-grained quartz-schist like the harder part of the schists of Scheurberg. The strike of the schists is N. 10° W., and there are three sets of well-developed joints, S. 35° W., S. 45° W., and N. 40° W. The surface of the rocks is rather highly polished by sand blown across it by the wind, and there are several holes in it, the deepest of which is more than five feet deep. These holes are filled by the rain and hold water for a long time, unless it is used up

[1] Rep. of the Surveyor-General for 1901, p. 9.

by passing travellers. The place is well known, and is the only spot where water can usually be found on one of the chief routes between the river above Upington and the Langeberg.

Four small patches of quartz-schist with strikes of N. 15°—30° W. were seen between Scheurberg and Inkruip, but in this area generally the red sand completely covers the rocks.

The Kheis beds appear again in the long line of kopjes projecting from the sand at various intervals from near Gamotep to Klein Kuie, a distance of some 30 miles.

The southernmost of the Gamotep rocks is 300 yards long and 100 wide; it rises about 100 feet above the sand, and is visible from a considerable distance to the east. It is made of a very hard quartz rock, which has joints or divisional planes of some kind striking N. 10° W., and less numerous joints lying E. 10° S. The rock seems to be vein quartz, not a quartzite of sedimentary origin, and it is brecciated in places. A rough schistose structure with thin films of sericite makes the rock break into irregular lenticular masses in parts. The Gamotep rock proper is not visible from a distance, for red sand downs rise round it; it lies about a mile north-west of the prominent southernmost kop. It is a sand-polished surface of quartz-schist and mica-schist, about 450 yards long and 100 wide, with long and deep rock holes in it. The strike of the schists is N. 20° W., and the rock holes, of which the largest contained a sheet of fresh water about 50 yards long by 20 wide and 8 feet deep at the time of my visit, are elongated in that direction. The rock is just like that of Scheurberg. Small kopjes of the same rock project from the sand about a mile north-north-east of Gamotep, but the strike there is N. 10° W. Along the western side of the Gamotep Pan, which lies nearly 5 miles north-north-east from the water-hole rock, the quartz-schist is exposed, but it then disappears for several miles, to emerge again in Malanie Kop and along the western side of the two pans near it. The next outcrops are those of the Kuie Block, where the schists are exposed more or less continuously for a distance of 9 miles from south to north, and I was told that some small outcrops occur much further north along the same line (about N. 10° W.), between Sand Kuie and the Kuruman River, but the schists do not crop out in the Kuruman River, nor, according to information from various people, do they appear at the surface in the Molopo.

In the Kuie Block the rock is of quite the same type as at Scheurberg, chiefly quartz-schist, but quartzites and mica schists also occur. They are exposed over a great part of the floor of Kuie Pan, and make a long ridge, which rises to a height of more than 200 feet above the floor of the pan, on the west side of it, and smaller kopjes on the east and north-east. The strike of the rocks in the Kuie Block varies from N. 5° E. to N. 15° W., but the predominant direction is N. 10° W.

The rock forming the kopjes east of the pan is white or grey

in colour, and all parts of it show one or more glittering micaceous surfaces when broken. Under the microscope a thin section (1752) is seen to be made chiefly of quartz with many dusty intrusions scattered more or less uniformly through it, a little white mica, and some magnetite. The quartz individuals are of fairly uniform size, and neighbouring quartzes often fit closely together without the intervention of anything else, so that the distinction between them may be visible only when seen between crossed Nicols. The quartz does not show strain shadows. Many of the quartzes contain smaller ones differently orientated within them. The mica is colourless, and occurs chiefly between quartz areas, but very small flakes are enclosed by quartz. The magnetite often has crystalline form but it is usually collected in thin strings, layers seen in section, parallel to the schistose planes in the rock. There are a few small highly refracting and doubly refracting prismatic crystals of a pale yellowish brown colour, probably zircon.

The rock exposed on the floor of the pan is green, as is often the case with rocks in salt or brak pans. In a well at the edge of the pan the quartz-schist is seen to keep the green colour at least 30 feet below the surface. It has a bright green colour, and the schistose structure is well developed. A thin section of this rock (1751) is seen under the microscope to be made of quartz, mica, garnet, and a very little magnetite. The quartzes are of uniform size, and are generally like those in the rock just described, but the dusty inclusions are less frequent, though there are layers of a dusty material along the surfaces of contact between neighbouring quartzes and in narrow zones within the quartzes parallel to those surfaces, also along the cleavage cracks of the mica. Instead of having the brownish colour of the inclusions in the grey rock just described, they have a greenish yellow colour in transmitted light under the microscope and are evidently the colouring matter of the rock. The quartz shows no strain shadows. The mica is colourless itself, but owing to the greenish dust along the cleavage planes and between this mineral and the quartz, patches of the mineral larger than the smallest flakes have a green tint under a low power. The garnet is in small grains, in some cases with crystal faces; it is colourless, and quite isotropic.

The quartz veins in this neighbourhood are chiefly of the sugary type.

Below Sterkstroom on the Orange River there are no rocks that can be referred to the Kheis series for some 20 miles down the river, where the kopje on which the Brak Pan beacon stands is formed by quartzites of uncertain relationship. About 10 miles beyond this kopje, and separated from it by later rocks the typical quartz of the Kheis series reappear on the farm Koras. These schists are brought up against the Koras conglomerates along a fault which trends north-west, but for about a mile near the river there is a mass of intrusive diabase (see

p. 86) along the fault; this diabase is of the same type as that forming intrusions at Groot Drink and Leeuw Draai. From Koras the schistose rocks extend continuously down the river past Uizip beacon to the farm Melkstroom, whence they stretch north-westwards through the north-eastern part of Upington Common. They also form a considerable range of hills between Steenkamps Pan and the Common. Though these rocks below Koras are chiefly quartz-schists, identical in character with those of Kheis and Scheurberg, they also include great thicknesses of other varieties of rock, which are either not so well developed in the east or have not yet been found there.

On Koras these rocks are highly disturbed but the dominant strike is about east and west; further from the Koras fault the strike lies between north-north-west and north-west, with high south-westerly dips. They include quartzites, quartz-schists, mica-schists, and phyllites of a dark colour and much finer texture than the usual mica-schist. On Uizip and Kameel Poort there are many bands rich in magnetite, but quartzites and greatly crumpled mica-schists make up the larger part of the rocks here. There are also thick bands of a brownish quartzitic looking rock on Kameel Poort with sub-conchoidal fracture; it has a peculiar mineral composition. Under the microscope (1796) it is seen to consist largely of quartz, which has a strongly schistose structure; the quartzes are all elongated in one direction and the larger individuals show strain shadows; the other constituents are monoclinic pyroxene, colourless amphibole, calcite, and magnetite. The pyroxene is colourless, and has the optical properties of colourless augite, but the prismatic cleavages are not well devloped; it occurs in rather large irregularly shaped masses, which enclose small round areas of quartz and also magnetite and flakes of amphibole; it is not arranged in any uniform way nor is it strained like the quartz, so it must have been developed subsequently to the schistosity of the rock. The amphibole is similarly independent of the schistose structure, forming small flakes, distributed irregularly through the rock; it is colourless and not fibrous, with extinction angles up to 18°. The amphibole, like the augite, is quite fresh. The calcite occurs in small patches throughout the thin slice examined.

There is no intrusive rock seen in the immediate neighbourbourhood of this quartzitic rock which would account for the development of new minerals. Some amygdaloidal lava of the Koras series is within a few hundred yards of this rock, but even if the lava outcrops mark the position of a vent, which may be the case, the pyroxene and amphibole in the schist are evidence of too great a change to be attributed to the proximity of the lava.

Near the fault on Koras there are large masses of a conglomeratic rock, with a matrix of mica-schist and lumps, some of them rounded at the edges, of quartzite, quartz-schist, and

vein quartz; this is almost certainly a crush-breccia and not a conglomerate of sedimentary origin; neither here nor in any part of the Kheis beds hitherto surveyed have undoubted sedimentary conglomerates been observed.

On Uap thin layers of hornblende-schist, often only half an inch thick, are interbedded with the quartz-schist and some of them were traced through 300 yards without change. In one case the hornblende-schist layer gradually thinned out, just as a sedimentary bed of different composition from the rest might do. These hornblende-schists were not found to cut across the quartz-schists.

The Kheis beds of this area are bounded on the south-west by the Upington granite as far north as the farm Christiana, where the Karroo formation covers both the older groups. Between the typical rocks of the Kheis series and the massive granite of Upington Common there is a belt of schistose rocks, the origin of some of which is doubtful, but as a whole they appear to be the contact zone of the great granite intrusion. There is no sharp line of demarcation between the massive granite and the bordering gneisses on the one hand, nor between the latter and the typical quartzites and quartz-schists on the other; bands of gneiss occur in amongst the quartz-schists within a mile of the boundary.

Just below the Government Offices at Upington there is a large mass of mica-schist surrounded by granite which sends many veins into the schist. The veins are exposed in the road cutting down to the drift and near a tunnel cut through the schist for the water-furrow. The schist is much contorted; the main surfaces of its contact with the granite lie nearly north and south, and are more or less vertical.

In the angle between the Hygap and the left bank of the tributary from Grond Neus there is a small inlier of granite and schist surrounded by quartzites of the Zwart Modder series (see p. 31 and fig. 1). The schists, which may be placed in the Kheis series, strike N. 25° W. They are mica-schists and garnet-sillimanite schists, which will be described below.

## The Granite and Gneiss of Gordonia, and their relation to the Kheis Series.

The first mass of granite met with on the right bank of the Orange River below Buchu Berg is on Spitzkop and Rooi Lye (see fig. 2). It is a wedge-shaped prolongation of a larger area in the Kenhardt Division. The rock is red in colour, owing to the red felspar in it and in many parts it has a strongly developed gneissose structure, the foliation planes lying parallel with the schistose planes in the Kheis beds near it; in other parts it is a hard compact rock with little mica, and shows no foliation.


FIG. 1.—Plan of inlier of schists (A) and gneissose granite (G) in sandstones and quartzites of the Zwart Modder series (S). The alluvium and gravel mark the position of the beds of the Hygap and the valley from Grond Neus.

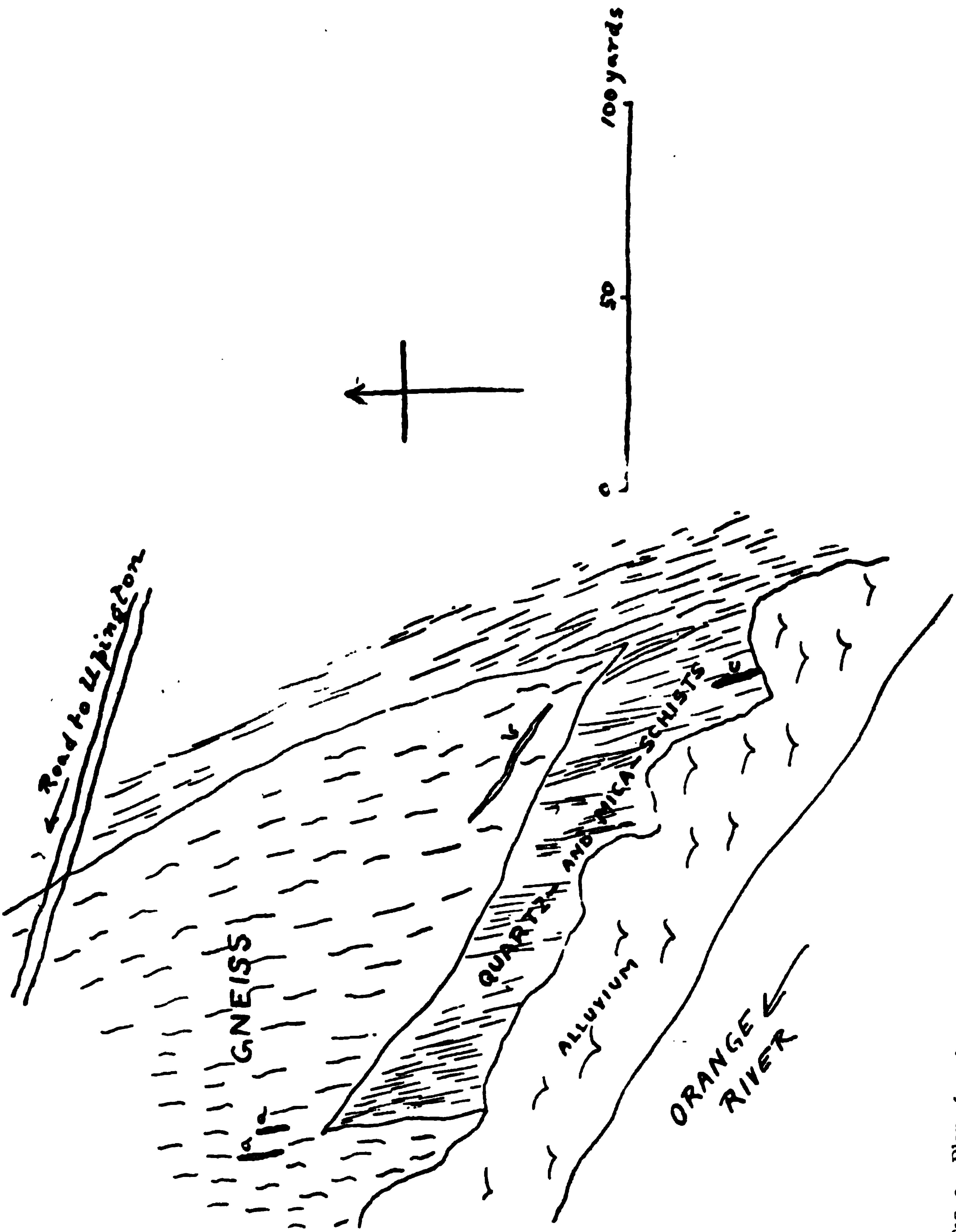



FIG. 2.—Plan of gneiss and Kheis beds on Spitz Kop. *a*, Quartzitic bands in the gneiss; *b*, quartz-felspar vein; *c*, hornblende-schist.

It is rather deeply weathered into a gritty mass, but the felspars are not much decomposed. Three thin sections (1771-3) from this gneissose granite have been examined; all of them show the effects of crushing. A red gneiss from Spitzkop (1771) is made of quartz, felspar, white mica, chlorite and some epidote. Most of the felspar is microcline, often in rather large patches of irregular shape, more or less completely surrounded by a zone of quartz or quartz-felspar mosaic; a similar mosaic occurs in bands traversing the slice. Some of the felspar is probably orthoclase and is crowded with small flakes of sericite. Both the quartz and felspar are crossed by many lines of minute inclusions or holes lying nearly perpendicular to the foliation; the larger individuals of both quartz and felspar show strain shadows. Another gneissose rock from Spitzkop (1772) is made of microline, quartz, and an acid plagioclase, and muscovite; it has been broken up, and the fragments of quartz and felspar are set in a matrix of quartz and felspar mosaic with sericite, the latter mineral also fills small cracks in the fragments and wraps round them. A massive-looking rock from Rooi Lye (1773) is seen in thin section to have been crushed; the large fragments are of quartz microcline and acid plagioclase, which are enclosed in a matrix largely made of quartz and albite.

This gneissose granite is traversed by veins of white opaque quartz containing pink orthoclase felspar in small patches; the veins usally lie parallel to the foliation of the gneiss, but they cut across the foliation in places; one of them is 50 yards long and 2 feet thick. They are like the quartz and felspar veins which occur in some dolomites at Zeekoe Baard in Prieska.[1] They are certainly of the same nature as the usual quartz veins found in rocks of various kinds, and are not of igneous origin in the sense that a dyke of granite is.

The contact of the gneiss and the Kheis beds is well exposed near the river on Spitzkop. Some specimens were taken from what were considered to be Kheis beds at various distances from the junction, and thin sections from them are described below. The contrast between the red gneissose granite and the grey schists is very marked in the field, but excepting the absence of microcline from the schists the two groups of rocks are in many ways very much alike as seen under the microscope. A slightly micaceous quartzite (1763), a grey rock striped with rather darker bands, and having a conchoidal fracture, taken from about 200 yards from the granite, is made chiefly of quartz in areas of more or less uniform size, without quartz mosaic between them; no strain shadows were noticed. Muscovite occurs in small flakes between quartzes or enclosed in the quartz grains; the flakes are often placed parallel to each other, but not in all cases. Magnetite is present in small quantity. No

[1] Ann. Rep. Geol. Comm. for 1899, p. 78.

felspar was seen. Cracks in the rock are filled with quartz mosaic. There are a few small grains of zircon (?) without crystal faces.

A similar looking rock (1764) 40 yards from the gneiss has a fair amount of epidote and some striped felspar. The quartzes are elongated in one direction, and most of the muscovite flakes lie in the same direction with which the strings of epidote grains are also parallel. There is a little magnetite and chlorite. The quartzes show slight strain effects.

A rock (1765) with the same constituents as the last, with the addition of calcite along broken bands, was taken at 30 yards from the granite. The schistose structure is well developed.

A rock (1766) 12 yards from the contact has the same constituents as those from 30 and 40 yards, but the epidote is in much larger quantity and there is more chlorite; there are also some ill-developed crystals of apatite and grains and crystals of zircon and sphene. The parallel arrangement of all the constituents is very strongly marked, and the quartz and felspar are traversed by lines of very minute, dusty inclusions and holes arranged perpendicularly to the planes of schistosity; the epidote is frequently cracked in the same direction.

A specimen (1767) taken from within a foot of the gneiss is made of the same constituents. The quartz and felspar areas are less equal in size, and there are streaks of quartz-felspar mosaic parallel to each other, but perpendicular to the lines of minute inclusions; it is only in the parallel bands of mosaic that the schistose structure of the rock is seen. A second specimen (1768) of rock taken from the contact at another spot has a very similar character, but it contains some apatite.

Two short bands of grey quartzitic rock were noticed lying in the red gneiss within 10 yards or so of the contact; they are only three or four inches thick and a few feet (under 15) long. Under the microscope (1769, 1770) they are seen to consist of much quartz and less felspar, which is chiefly an acid plagioclase, though some microcline is also present, a fair amount of chlorite, a little muscovite in very small flakes, and patches of a much cracked and partly decomposed, highly refracting isotropic, colourless mineral, probably garnet. The quartz and felspar are in areas of fairly uniform size, and are only slightly elongated parallel to the schistosity; the chlorite is chiefly arranged in the same direction. The lines of brownish dusty inclusions are perpendicular to the schistosity, and the larger specks are seen under an eighth-inch objective to be holes probably filled with liquid. This rock differs from the other schists in the presence of a small amount of microcline.

The most quartzitic members of this group of schists are without doubt very similar to, or identical in character with, a great thickness of rock belonging to the Kheis series, and the increasing amount of felspar and epidote is probably to be attributed to the influence of the granite. If the latter were not an intrusion

but an older rock upon which the Kheis beds were laid down, one would expect to find the felspars in the schists considerably altered, whereas they are fresh, as though they are newly-developed minerals. If they were debris from a pre-existing granite, they would probably be chiefly microcline and orthoclase, but they are chiefly, at least, an acid plagioclase. The rocks found as inclusions in the gneiss, though taken in the field to be fragments of quartzite, may have had a different origin, though it is possible that the microcline substance in them came from the gneiss, and that they are really sedimentary rocks, with more additions from the granite than were given to the enclosing schists.

The rocks have certainly been considerably disturbed since the intrusion of the granite, for the latter, in addition to the gneissose structure, has been broken up, and the parts re-cemented by quartz-felspar mosaic. This fracturing process has had the effect of obliterating the foliation of the rock to some extent, and was probably brought about long after the foliation, which, as it is parallel to the schistosity of the enclosing rock, may have been produced during the intrusion or before the rock finally cooled.

On Leeuw Kop there is another wedge-shaped prolongation of granite on the right bank of the river; it is a red gneissose rock like that of Rooi Lye and Spitzkop, and the foliation is parallel to the schistose planes in the immediately surrounding Kheis beds, striking about N. 15° E. The schists here are of the same character as those on Spitz Kop, but they have not been studied under the microscope.

On Zwem Kuil there is a thin band of highly micaceous gneissose granite in the schists, which here contain very much mica, and are in consequence more deeply disintegrated than usual.

Between the Melkstroom-Steenkamp's Poort hills and the granite of Upington there is a band of schistose rocks, quite a mile wide across the strike, which differ in some respects from the ordinary quartz-schists of the Kheis series. Some of these rocks have been examined under the microscope.

A rock on Uitkomst (1801), taken for a quartzite in the field, consists chiefly of quartz with strongly marked schistose arrangement; large neighbouring quartzes are often separated by quartz mosaic, and the large quartzes always show strain shadows; there is a small amount of felspar, some of which is plagioclase and some untwinned; it is rather cloudy, and some of it contains many small flakes of sericite. There is also a small amount of white mica and greenish weathered biotite, and a very little magnetite, sphene, and zircon in minute crystals. Three other slices (1802-4) from rocks on the same farm are

similar to the above in general character, but have somewhat more felspar, and part of the felspar is microcline; they also contain epidote and chlorite, the former of which appears to have developed from felspar. In one slice (1804) the muscovite is in much larger flakes than usual, but does not show the strain effects exhibited by the large quartzes in the same section.

A rock (1808) from the same belt of schists at a place in Upington Common, about eight miles north of the main road south of the granite kopje, is made almost entirely of quartz, felspar, sericite, magnetite, or ilmenite and sphene. Another rock (1809) taken from a spot a mile south of the last, forms part of a more felspathic-looking band lying in the quartz-schists. Under the microscope, it is seen to be a fine-grained rock, made of quartz, felspar chiefly untwinned, but some plagioclase is present, muscovite, chlorite, pseudomorphs often biotite, magnetite, apatite, and calcite. The chief constituents have a marked parallel arrangement. Much of the untwinned felspar is cloudy and contains small sericite flakes. This rock is evidently a fine-grained gneiss, and coarser gneisses were seen forming other bands in the schist belt in the neighbourhood.

This schist belt bordering the Upington granite is probably of various origins; some of the bands are almost certainly altered sedimentary rocks, and others are certainly gneiss of igneous origin.

The Upington granite area has been examined only in part. Like the smaller granite areas described above, it is the northern end of a large mass, extending into the Kenhardt Division. The width of that part of the area on the north bank is not known, but it stretches from Melkstroom beyond Upington village. The granite passes under unconformably overlying rocks between Christiana and the Hygap.

Generally the granite rock is covered by a coarse sandy soil, partly derived from the immediately underlying granite or gneiss. The more massive varieties occasionally form bold "tors," hills of naked granite, usually made of very large rounded blocks, separated by spaces, except at the points of contact. The spaces are due to weathering along joints, and the removal of the debris by wind and rain. There are several of these peculiar kopjes on Upington Common; a good example lies near the main road, through the south-eastern corner of the Common, and another close to the most used main road to Zwart Modder, nine miles out of Upington. They look as if made of blocks thrown down in a heap. On Blaauwbosch there are similar kopjes, and also remarkable boulders of great size left balanced on small surfaces.

Where the rock is well foliated, as in the immediate neighbourhood of Upington village, the kopjes assume a more ordinary form, for the rock weathers more uniformly from the exposed surface inwards, and the joints have not the same im-

portance in determining the incidence of the weathering processes as in the massive granite.

Depressions in the surface of the granite, due to the removal of the weathered debris, are not often seen in this area, but a well-known water-hole, about 10 miles from Upington, on the Zwart Modder road, is of this nature; it is a long hole, about 12 feet deep at present, and is due to weathering along a north-south joint. It is unlikely that a hole of this sort at the general level of the country would be hollowed out by the wind alone; as in the north of Van Rhyn's Dorp,[1] artificial excavation would seem to be necessary before the hole served a useful purpose, but I could not discover whether this water-hole had been dug out within recent years.

There are several varieties of granite in the surveyed part of the Upington mass. There are various gradations between a quite massive rock and well-foliated gneiss, and in composition the rock varies from a biotite-granite, with little or no hornblende, to a hornblende-granite, and there are also bands of hornblende—and pyroxene—granulite.

A specimen (1806) taken from one of the first massive-looking outcrops met with as one approaches Upington Common from the east is found, under the microscope, to consist of quartz, felspar, biotite, green hornblende, sphene, magnetite, and apatite. The structure is usually granitic without porphyritic constituents, but there is a considerable amount of micropegmatite, and also bands and patches of quartz-felspar mosaic. The felspar is chiefly microcline, but there is some untwinned felspar, which is usually cloudy, and contains much sericite. Neither the hornblende nor biotite form well-shapen crystals. The hornblende is a rather deeply coloured and strongly pleochroic green variety; the biotite is brown and strongly pleochroic. The sphene is in rather large, irregular pieces; it is twinned and slightly coloured and pleochroic. The magnetite and apatite are in small quantity. All the minerals are strained, but the hornblende shows less effect of the straining than the others. A fine grained, somewhat schistose, band traverses this massive rock, and in thin section (1870) it is seen to be made of pieces of quartz and felspar (microcline and acid plagioclase), set in a matrix of smaller fragments of the same minerals, together with some epidote. There are also fragments of magnetite, sphene, and apatite. The rock has a distinct banded structure, owing to the arrangement of the fragments, with their longer axes parallel. The band, which is evidently a zone of fracture, runs N. 25° W., approximately in the same direction as the strike of the nearest Kheis beds and their line of junction with the granite.

The prominent granite kopje, mentioned above, on the east side of the Common, is made of a rock which looks massive on

[1] See Ann. Rep. Geol. Comm. for 1904, p. 12.

the outcrop, but a parallel arrangement is noticeable in a thin section (1811), and the larger quartzes and felspars are cracked perpendicularly to this structure. The rock consists of quartz, microcline, orthoclase, biotite, muscovite, magnetite, or ilmenite, and very small quantities of zircon, sphene, and apatite. Much of the quartz and some felspar is in the form of a mosaic of larger-sized individuals than those of the mosaic in the crushed granite just described, but the mosaic is evidently the result of a similar process to that which gave rise to the crushed band. The biotite is in rather small irregular flakes, and is partly changed to chlorite. The muscovite is also in small flakes, and may perhaps be an alteration product.

The Upington kopje, on which a beacon of the geodetic survey stands, is made of various gneissose and banded rocks traversing more massive granite. The foliation and bands dip towards W. 20° S. The bulk of the ridge is a rock taken in the field to be a grey hornblende gneiss, but microscopic examination proves it to be an augite-granulite. The constituents (1812) form nearly equal-sized areas, and are always allotriomorphic; they are felspars, a green monoclinic pyroxene, and small quantities of quartz, sphene, hornblende, and epidote. Most of the felspar is plagioclase of a variety near andesine, but there is some untwinned felspar, cloudy with alteration products, amongst which sericite is the most abundant. The pyroxene is a green monoclinic variety, and is scarcely pleochroic; the prismatic cleavage is not well-developed. The hornblende is a green pleochroic sort, and has a well-developed prismatic cleavage; it is the same kind of hornblende as that seen in the hornblende schists or amphibolites of Gordonia, and it is not uniformly distributed through the rock, but occurs in some bands only. The epidote is chiefly found with the hornblende, but small quantities are in some of the felspars. Sphene occurs in grains without crystal faces. This rock is traversed by veins of hornblende granite, which is seen in thin section (1813) to be made of quartz, microcline, orthoclase, hornblende, sphene, and a little zircon and apatite. The orthoclase is cloudy, otherwise the rock is quite fresh. The hornblende is a strongly pleochroic green-brown variety.

Coarse pegmatites occur in veins traversing both the granulites and the granite veins.

A dark, well-banded rock (1814) from this ridge is found to be a hornblende—pyroxene—granulite, made of hornblende, monoclinic pyroxene, quartz, felspars, and a little sphene and epidote. The hornblende and pyroxene are the same minerals as are in the hornblende-granite and the pyroxene-granulite described above, but they are collected together in more or less definite bands, which give the rock a very dark colour. Much of the felspar is a variety near andesine, but there is some orthoclase, partly altered to cloudy sericitic patches, and there are also a few grains of microcline. Quartz is less abundant than the felspar.

On the left bank of the Hygap, on Ghous, just below the junction of the tributary from Grond Neus, there is a small inlier of granite and schist. (See fig. 1.) The granite is slightly foliated, and is seen under the microscope to be made chiefly of quartz, orthoclase, and brown biotite, with a small amount of repeatedly twinned plagioclase. The slice (1816) shows a pronounced parallel structure, which is at least partly due to crushing and a fresh development of quartz and felspar. The biotite is much bent and broken. All the constituents show optical anomalies, due to strain. The parallel structure runs N. 25° W., parallel to the bands and schistosity in the schists in the outlier.

The schists occur on the north-east side of the granite, and also as great masses in the granite, separated at the surface from the main mass of the schist. (See fig. 1.) They consist of quartzitic rocks, quartz-schist and sillimanite-schist. Two slices have been cut from the latter rock, and they show several interesting features. One section (1817) consists of quartz, garnet and sillimanite in abundance, and also red mica, white mica, felspar, magnetite, and pyrites. The quartz alone shows a distinct parallel arrangement, but other constituents, especially garnet, are cracked perpendicularly to the long quartzes; the quartz is much strained and broken, except those small pieces entirely enclosed by garnet. The garnet is pink in the hand specimens, but colourless and quite isotropic in thin section; it encloses portions of all the other constituents. There is a small amount of a deep green isotropic mineral, with as high refraction as that of the garnet; it is either a green garnet or, more probably, a spinel. The sillimanite is in fibrous masses and in large prisms; the latter are broken, and show irregular extinction; the mineral is scattered irregularly through the slice. The red, strongly pleochroic mica is in small flakes and aggregates; it often also fills cracks in the garnet, and lies parallel to the walls of the cracks; small round pieces are enclosed by the garnet. The felspar is much altered into a mass of sericite and zoisite, but parts show repeated twinning.

The second slice (1818) has the same constituents as the other, but they have a more pronounced parallel arrangement, owing to sillimanite, garnet, and some of the mica adapting themselves to the parallelism of the long quartzes. In this slice the colourless garnet is less abundant, and the green isotropic mineral much more abundant than in the other.

## GRANITE AND ASSOCIATED ROCKS OF THE VRYBURG DIVISION.

The granites and allied rocks of Vryburg are limited to the country north and east of the Black Reef escarpment, which trends westwards from near the town of Vryburg to Garophoane, on the Mashowing, and thence east-north-east through Morokwen.

Though this group of rocks is seen at the surface in many places, and has been met with in wells over a large area, it is frequently concealed under sand and other surface rocks. It differs chiefly from the Gordonia granite group in not having been found as an intrusion in older rocks corresponding to the Kheis beds of Gordonia, though further to the north-east some highly metamorphosed rocks, probably of sedimentary origin, were found associated with granite which is continuous with that under description.[1]

The Vryburg granite does not form prominent hills like those near Upington; only near the escarpment immediately west of Motiton were outcrops of considerable height seen, though along the Mashowing bed and in the Mokgalo, Kgogole, and Genesa laagtes occasional large bare surfaces of granite are exposed, and there are similar outcrops near the large pan on Morokwen.

The granitic rocks crop out occasionally in the Thlakgaming laagte, which passes through the eastern end of the Genesa Reserve. The upper part of this dry valley is called the Doorn laagte, and in it a few outcrops of massive pink biotite-granite appear, and weathered rock of similar character, though sometimes foliated, is thrown out from wells in the laagte. Near the Thlakgaming location, the granite contains enough epidote to give the outcrops a green colour. On Reitzdale the granite is weathered to a depth of 90 feet, as proved by the rock thrown from a well.

In the Genesa laagte gneiss and granite crop out occasionally. In one of the head valleys of this laagte, on the farm Boschbult, a well has been sunk 140 feet deep; the weathered granite was struck at 17 feet, and solid granite at 120 feet. The rock is partly gneiss and partly massive biotite-granite; coarse pegmatite veins traverse both varieties. A thin section (1718) from a granite shows this rock to be made of quartz, microcline, an acid plagioclase, orthoclase, biotite, muscovite, apatite, and magnetite. The structure is typically granitic. The microcline and plagioclase are the most abundant felspars. The muscovite and biotite are in small quantity only, and the latter is partly changed to chlorite. The minerals, especially quartz, show strain shadows. Another slice (1719) from a granite, taken from 20 feet down a well on Ganna Laagte, a neighbouring farm, shows quite similar characters.

The foliation planes of the gneiss near Genesa trend about N. 15° E., and there are coarse pegmatites traversing the rock.

For many miles south of the massive granite outcrops in the Morokwen pan the granite is concealed, but it has been struck in wells in the Pepani laagte about 9 miles from Morokwen. Near Mrs. McKee's house a well sunk 130 feet through a sandy surface rock did not reach the granite, but further south, in the laagte, granite was met with 50 feet below the surface, and the well was

[1] Du Toit, Ann. Rep. Geol. Comm. for 1905, pp. 209—213.

sunk 340 feet without entering other material. A specimen (1824) taken from near the bottom of this well is made of quartz, plagioclase, microcline, orthoclase, chloritised biotite, a little muscovite, magnetite, and a fair amount of calcite. The microcline is not abundant. The rock is a massive granite.

No outcrops were seen in the Matamatobo laagte, but large surfaces of massive granite and one gneiss outcrop were seen in the Kgogole laagte on Kgogole and Ophir. These rocks are traversed by many veins of pegmatite. The smaller veins, those not more than 12 inches wide, have a peculiar structure; the sides are lined with a coarse rock formed by large plates of muscovite and biotite up to three inches wide, standing perpendicularly to the walls, and embedded in a coarse quartz-felspar matrix, the few inches between the coarse mica rock are filled in with a granite of apparently the same nature as the enclosing rock, a medium-grained biotite-muscovite-granite.

Large outcrops occur on Tlaping, on the Mokgalo laagte.

Granite and gneiss frequently appear at the surface for some 20 miles below Motiton in the Mashowing valley, particularly within 300 yards of the river bed.

Throughout this valley the rocks are moderately coarse, but they are not porphyritic. Bands of gneiss are seen, but they do not seem to be separate intrusions, and pegmatites cut both granite and gneiss. The foliation of the gneiss strikes about N. 15° E.

Near Takoon, in the Motiton Reserve, a large part of the rock is a hornblende granite, made of quartz, acid plagioclase, a little orthoclase, a strongly pleochroic green hornblende, a little biotite mostly altered to chlorite, apatite and magnetite (1632). The untwinned felspar is much altered. Further down the valley near Motiton a specimen from which a thin slice was cut (1626) is made of quartz, microcline, orthoclase, repeatedly twinned acid plagioclase, chlorite after biotite, apatite, magnetite, and a little calcite. Quartz forms intergrowths with the three kinds of felspar. A band of pale granite traversing this rock is made of the same constituents (1627), but it contains no quartz-felspar intergrowths, and there is a fair amount of epidote.

A gneiss from Kobogo (1722) is composed of quartz, acid plagioclase, and orthoclase, which often form intergrowths, together with small amounts of biotite, muscovite, and magnetite.

## HORNBLENDE-SCHISTS OF GARAPHOANE.

The granitic rocks were not seen below a point about five miles below Masilibitsani, from thence to Garaphoane the surface deposits conceal the underlying rock. At Garaphoane the Black Reef escarpment crosses the river, and on the right bank, the rocks below the quartzites are exposed for a short distance. The lower rocks consist of dark hornblende-schists or amphibolites, often with a strongly-developed parallel structure, strik-

ing about N. 10° E., and lying nearly vertically. The total thickness of schists exposed is about 1,200 feet. They are traversed by many veins of white quartz. The easternmost outcrops are very fine grained, almost black, fissile rocks, in which no constituents can be seen with the unaided eye. Under the microscope, the rock (1730) is seen to consist of very small irregularly-shaped fibres and plates of pale, scarcely pleochroic, actinolite, usually arranged parallel to one another or in feathery aggregates; these are set in a matrix of a colourless mosaic, apparently of quartz; the only other constituent recognised is magnetite in minute crystals. This rock is followed westwards by several hundred feet of a coarser schist, made largely of a more deeply coloured green-blue-yellowish pleochroic hornblende which is also more strongly birefringent than the paler mineral in the other rock (1729); the only other constituents are quartz and a small amount of magnetite. The westernmost outcrops, which are directly overlain by the Black Reef quartzites are coarser actinolite-schist; this consists chiefly of pale, slightly pleochroic actinolite, with a small amount of clear mosaic, probably of quartz, and a few grains of zoisite (1726). Much of the actinolite has a parallel arrangement, and none of it shows crystal outlines. Interbedded with these fissile rocks there are bands of black massive rock, with little or no tendency to split parallel to the prevailing strike of the schists. Under the microscope, this massive rock (1727-8) is found to consist of the same minerals as the schists, but without a parallel arrangement. The pale actinolite is in ragged pieces in a colourless matrix, which seems to be chiefly quartz, but quartz also occurs in much larger patches. No felspar was recognised, but there is some cloudy material associated with the small quartz mosaic. Zoisite and magnetite, or ilmenite, and leucoxene are also present.

## THE KRAAIPAN SERIES.

Rocks which must be placed in the Kraaipan series occur on the eastern side of the Motiton Reserve and the country east of it, and possibly also on the farm Clapham, near Garaphoane.

The Motiton occurrence is certainly a continuation of the strip of Kraaipan beds on Kameel Rand and Hamburg, described in last year's Report.[1] The rocks make a distinct ridge, trending east and west parallel to their strike, though they do not crop out frequently. On Waai Hoek, quartz-porphyries are seen at the surface, and less frequently the magnetic quartzites crop out. As on Kameel Rand, the soil on this ridge has a much deeper red colour than on the granite and volcanic rocks (Pniel group) to the north and south.

In the western corner of Waai Hoek some prospecting trenches have been cut, and they expose a succession of magnetic

[1] Ann. Rep. Geol. Comm. for 1906, p. 12.

quartzites, followed by three feet of quartz-porphyry, with another band of magnetic quartzites above it; then comes a considerable thickness of chloritic schists or phyllites, which are deeply weathered. All these rocks dip at about 45° slightly west of north. The junctions with the granite both to the north and south are hidden, but the latter rock crops out between this belt of schists and quartz-porphyry and a smaller one, which lies about a mile-and-a-half further south. The existence of the southern belt was only determined by the presence of a few outcrops along the road leading down the hill to the upper end of the Mashowing valley and the occurrence of a strip of deep red sand, which in this neighbourhood certainly indicates the presence of highly ferruginous rocks under the soil.

The magnetic schists seen are rather coarse rocks, containing much magnetite; they are distinctly banded and resemble closely some of the rocks in the Kraaipan series in Mafeking.[1] The quartz-porphyry is a pale pink or grey rock with quartz blebs and crystals, and a flow structure can be seen on the outcrops. Under the microscope (1720) the quartzes, passed through by the one slice cut, are angular and without crystal faces; they include small round patches of the ground mass. The ground mass consists of a micro-crystalline mixture of colourless minerals, amongst which quartz and muscovite can be recognised; no felspar was detected. A few flakes of muscovite are larger than the usual minute flakes in the ground mass. The structure of the matrix is micrograniṭic and no micropegmatite is visible.

Further cuttings in the northern belt, on Motiton ground, have been made since the locality was visited by me, but they have not been examined by the survey.

Lying in the sandy soil behind the Black Reef escarpment on Clapham, there are blocks of fine-grained banded magnetic quartzites too large and numerous to have been carried there. As the spot is at a rather low level it is possible that the fragments indicate the presence of an inlier of the Kraaipan formation within the Black Reef belt, but no outcrops were seen. On the other hand they may be ferruginous beds like those in the Black Reef series between Geluk and Zwart Fontein.

## THE WILGENHOUT DRIFT SERIES.

For a distance of some 10 miles down the right bank of the Orange River below Sterkstroom there is a group of very varied rocks, which cannot at present be definitely assigned to any described series, though in some respects they closely resemble rocks found in the Kraaipan series of Mafeking. When I first

[1] See Ann. Rep. Geol. Comm. for 1905, p. 232.

saw them in the field, a striking but superficial resemblance to the Vaal River and Transvaal systems was at once apparent, and some of the differences from the normal types of the latter groups were attributed to the effects of earth movements; but at the time one very great obstacle to their correlation was obvious, viz., the question how the lavas and agglomerates of the Koras group, which seem to belong to the Vaal River system, could have escaped the effects of the earth movements which sheared the Wilgenhout Drift beds. Subsequent study revealed other dissimilarities from the Vaal River and Transvaal beds and resemblances to the much older Kraaipan rocks. As the beds occupy a larger area in the Kenhardt Division, which will probably be examined next year with the advantages gained by last season's experience and the results of microscopical investigation, it seems better to place them in a temporary group of their own than to assign them definitely to a position amongst the rock formations already described.

The Wilgenhout Drift beds are exposed between Sterkstroom and Leeuw Draai, but the succession is not a continuous one, for they are evidently traversed by a fault on Zwart Kop. (See figs. 3 and 4.) The structure of the area seems to be that of a syncline trending a few degrees east of north with a fault along the axis with downthrow to the east; the succession is more complete on the east than on the west of the fault. (See fig. 4.) On the east side the whole formation seems to be thrown down against the Kheis beds of Groot Drink along the Groot Drink-Sterkstroom fault, which trends about E. 30° N., but near the river there is a large mass of diabase (see p. 86) between the two formations. On the west side of the area the Wilgenhout Drift beds are again bounded by a mass of similar diabase, which certainly has not been affected by the earth movements that sheared the sedimentary rocks. Whether the boundary is a fault is not quite certain, but the straightness of the limit, which lies about north-north-east nearly parallel to the strike of the Wilgenhout Drift beds, gives it the appearance of a fault.

The lowest rocks assignable to the Wilgenhout Drift beds are some porphyries, the outcrops of which are meagre, so that their relation to the succeeding beds is doubtful. These rocks are dark greenish in colour, with white porphyritic crystals, which are as much as a third of an inch long. The matrix is fine grained. Under the microscope (1775), the porphyritic crystals are found to be entirely changed to sericite and other alteration products of felspar; they lie in a matrix made of augite, felspar and magnetite with a small amount of clear alteration products between them. The augite is very little altered; it is an almost colourless variety and never has crystal forms; it occurs in irregular grains and small ophitic plates enclosing wholly or partly very small laths of felspar; it has a basal striation slightly developed and is often twinned on (100). The felspar enclosed by the augite is the only felspar left unaltered;

it is a rather basic variety judging from the high symmetrical extinction angles in some twins. The magnetite crystals are

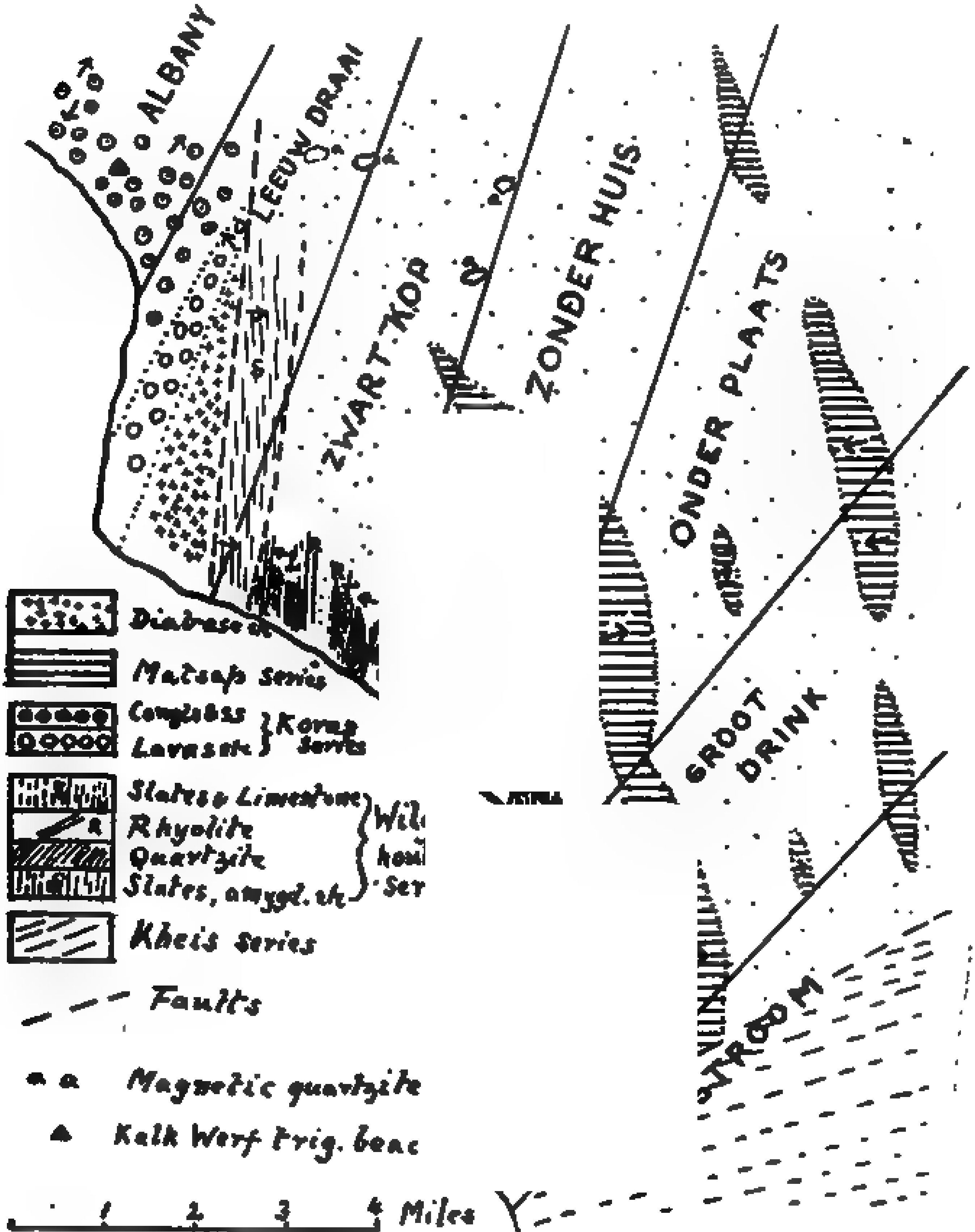



FIG. 3.--Plan of Wilgenhout Drift beds, etc., on the right bank of Orange River above Upington.

often arranged in two series of rows of octahedra, attached axially and crossing at right angles, as that mineral sometimes occurs in glassy basalts. The clear alteration products in the

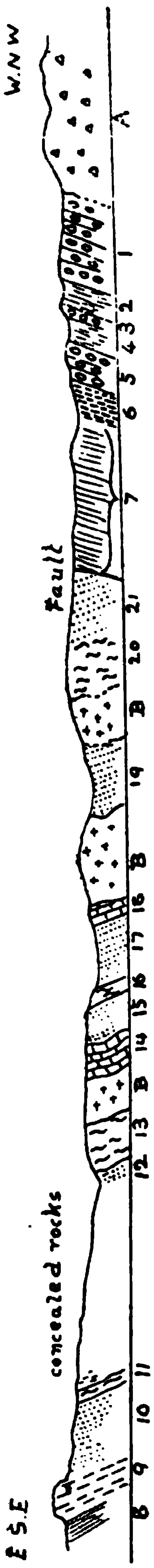



FIG. 4.—Section through part of the area occupied by the Wilgenhout Drift beds between the south-western corner of Zonderhuis and the diabase on Leeuw Draai—distance about 3,000 yards. A, intrusive diabase of later date than the cleaving of the Wilgenhout Drift beds; 1, amygdaloidal lavas and breccias; 2 and 4, slates; 3, conglomerate with green matrix; 5, amygdaloidal lavas; 6, slates, felspathic sandstones and quartz grits; 7, cleaved diabase tuffs and lavas, fault; 8, green phyllites of the S.W. corner of Zonder Huis; 9, red quartzites of Zwart Kop Kopje; 10, 12, 15, 17, 19, 21, grey tuffy beds; 11, 13, 16, 20, quartz-porphyries; 14, 18, limestones.

matrix of this rock probably represents a glassy base. This porphyry was only seen on Groot Drink, and its characters are so different from those of the lavas to the north-west that it is very doubtful whether it should be placed in the Wilgenhout Drift beds at all; but it is considerably more altered than the large diabase intrusions along the boundary faults though it does not show the effects of shearing that the Wilgenhout Drift lavas exhibit.

North-west of the porphyries there is a great thickness of green rocks, all considerably sheared; they include well-cleaved slates, amygdaloidal lavas and breccias containing lumps of the lava. In addition to these there are later intrusive rocks which, unlike the porphyry, have been sheared to the same extent as the sedimentary and volcanic rocks invaded. The intrusive nature of some of the green rock is obvious in certain places where the slates are penetrated by tongues of the former and contain flakes of mica within a few inches of the igneous rock, but not elsewhere (see fig. 5). The intrusive rock (1777) is made up of hornblende, quartz, ilmenite and leucoxene, sphene, epidote, chlorite, and a very little felspar. The hornblende is of two kinds, a green-blue, rather strongly pleochroic sort, in irregular plates which extinguish uniformly, and paler uralitic hornblende in fibres and aggregates. These two minerals made up the greater part of the rock; the quartz and other constituents form the ground mass, none of them have crystalline forms. It is possible that the larger plates of hornblende may be original constituents, but more likely that it is a fresh development like the other minerals, except ilmenite. The felspar seen does not look like original felspar; it is quite clear and in small grains, and is recognised by an occasional twin. This specimen was taken from the spot a in fig. 5; another slice from b (1778)

shows somewhat different characters, though it is is certainly part of the same rock mass from which the former came. The hornblende in the latter case is a very pale variety in elongated prismatic forms, which, however, do not show definite boundaries; these long hornblendes are to a considerable extent arranged parallel to one another, giving the rock a marked fissile structure. The rest of the rock is made of small grains of quartz and perhaps felspar, chlorite, and much ilmenite and leucoxene in short linear aggregates. A section (1779) cut from

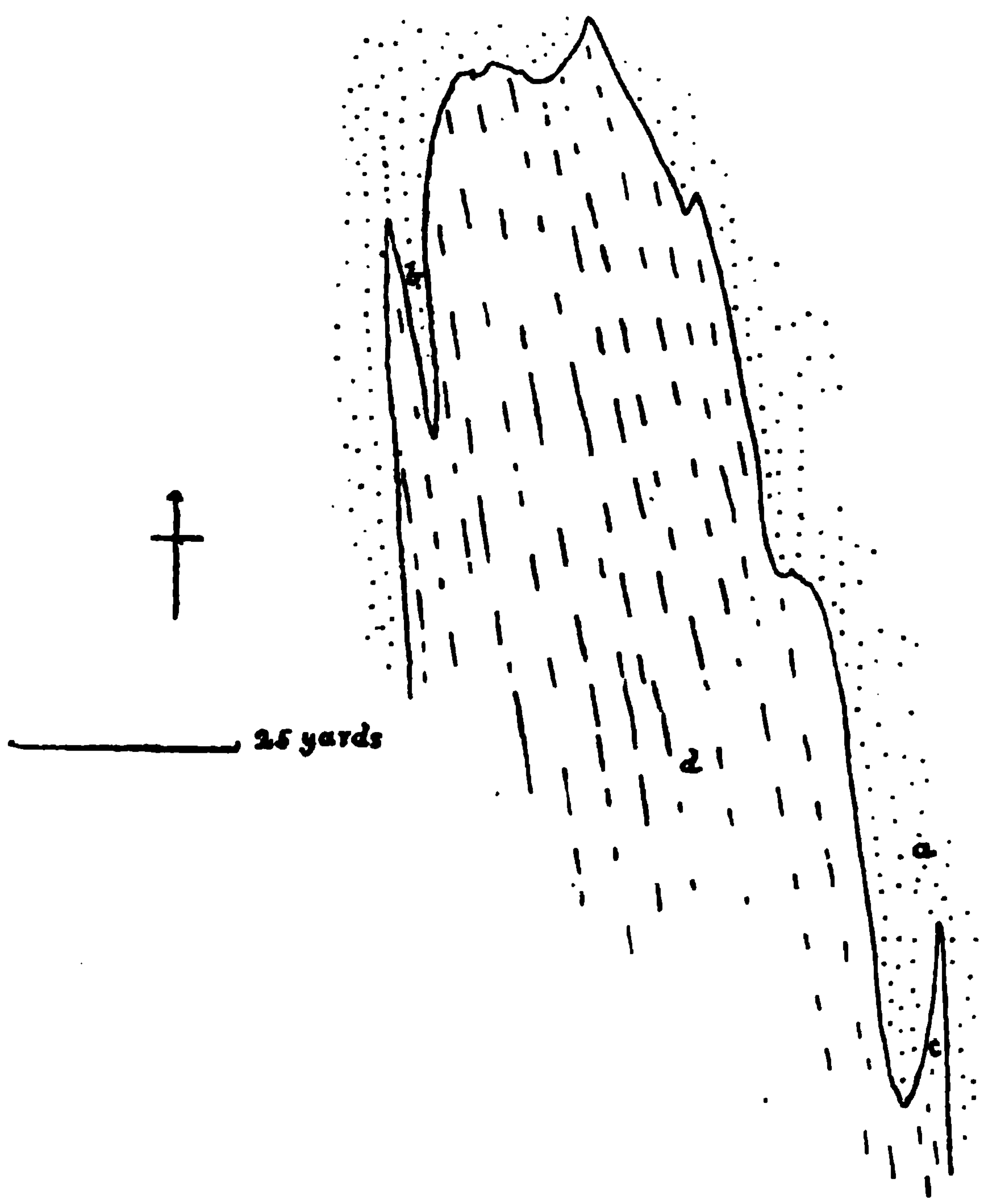



FIG. 5.—Plan of epidiorite and slate contact on Onder Plaats.
*a*, *b*, Epidiorite; *c*, *d*, slates.

the sedimentary rock from within an inch or two of the epidiorite, at c in fig. 5, shows a base consisting of a colourless porcellanite-like aggregate, containing minute flakes of chlorite, some undetermined highly birefringent grains, and irregularly formed flakes of mica of a peculiar reddish yellow colour, but with the usual optical characters of biotite.

In isolated outcrops of igneous rock on Groot Drink and Onder Plaats, surrounded by alluvium, it was found impossible to decide whether the rock was of the nature of an intrusion or a compact lava. A dark greenish rock forming a band ten feet thick between green slates on Onder Plaats is seen under the

microscope (1780) to consist of large ragged plates of colourless tremolite, a considerable quantity of epidote in large irregularly-shaped grains, and large masses of leucoxene with a little ilmenite left, chlorite and a colourless aggregate of minute quartz grains and probably also felspar. This is a coarser grained rock than the intrusion described above, and from the large size of the leucoxene patches, the only direct representatives of an original constituent, it would also appear to have been an intrusion.

The volcanic rocks were recognised by the presence of amygdales, often elongated and distorted by shearing, and these amygdaloidal lavas are associated with tuffs and breccias. The volcanic rocks are green, often rather bright green, owing to the large amount of epidote in them. Two slices cut from amygdaloidal lavas on Onder Plaats show that the rocks have been very much altered; no sign of the original structure beyond the presence of amygdales is visible, the slices are made of irregular interlocking areas of epidote and quartz, containing a large amount of magnetite in small shapeless grains, sometimes collected in patches and enclosing the amygdales, which are patches of quartz and epidote free from magnetite. One of the slices has a fair amount of granular quartz mosaic and some calcite in small patches.

On the slight rise on which the Onder Plaats house is built, the volcanic rocks are well exposed. There is a thickness of over 1,000 feet of green amygdaloidal lavas and breccias, but their original nature is much obscured. Their structure is best seen on weathered surfaces where the amygdales, when present, are seen, but on a freshly-broken surface it is difficult to recognise amygdales in the elongated pale streaks and patches scattered through the rock. The nature of the breccias is also more obvious on a weathered than on a fresh surface. These rocks are traversed by veins containing quartz, calcite, and epidote.

The main body of volcanic beds on Onder Plaats is succeeded by a great thickness, 5,000 feet or more, of slates without lavas, but lavas and breccias like those on Onder Plaats appear again on Zonder Huis, where they are accompanied by green quartz grits and conglomerates with green matrix. The pebbles in the conglomerates are chiefly quartzite and quartz-schist. These are succeeded by some thousands of feet of soft and rather deeply weathered green phyllites, which are directly overlain by about 200 feet of dark red quartzites on the Zwart Kop boundary. The quartzites form the kopje from which the farm gets its name. They do not contain isolated pebbles or bands of conglomerate, and have a uniformly dark colour, except in a few bands, which are paler.

The red quartzites are followed by pale greenish tuffy rocks of a considerable thickness but not well exposed; outcrops of a very hard greyish white porphyry mark the presence of a thin flow of quartz-porphyry similar to thicker bands of porphyry

higher in the series. For a distance of some 500 yards north-west of this porphyry the rocks were not seen, but the soil contains fragments of greenish-grey tuffy rocks, above which are outcrops of similar beds; then comes the thick band of porphyry. This rock shows a flow structure in the arrangement of the porphyritic crystals (felspar and quartz) and fine lines in the ground mass. The rock (1782, 1783) has suffered from the effects of pressure and the porphyritic quartzes are granulitised. The felspar seems to be of two kinds, an acid plagioclase and orthoclase twinned on the Carlsbad law. The ground mass is made of a microcrystalline mixture of quartz and felspar with micrographic structure; there is also a fair amount of a rather highly refracting alteration product, which seems to be zoisite, sometimes partly replacing felspar crystals. Small veins of quartz and calcite traverse the slices. The rock is probably an acid lava; it resembles the quartz porphyry found in the Kraaipan beds of Waai Hoek.

To the north-west of the thick quartz-porphyries there is an intrusion of altered diabase, epidiorite, a dyke-like mass about 300 feet thick; two other intrusions of the same kind of rock occur further west, and from one of them a thin slice has been cut. The slice (1784) shows large and usually quite irregularly-shaped plates of colourless amphibole, probably tremolite, often deeply penetrated by the ground mass; occasionally prism faces and a pinacoid truncating the large angles made by the prism faces are developed. The rest of the rock is made of a confused aggregate of small flakes of tremolite, epidote, chlorite, quartz and perhaps felspar, and a considerable amount of leucoxene in rather large patches.

To the west of the first diabase intrusion there succeeds a band of marmorized limestone, or dolomitic limestone, about 100 feet thick, with which irregular layers of grey chert are associated. The limestone is in part soluble in dilute acid; it is white or very pale grey in colour, and has a saccharoidal structure. It has no close resemblance to the Campbell Road dolomites except to those parts of the latter formation within a few inches or a foot of a dolerite dyke. The saccharoidal character of the limestone in the Wilgenhout Drift beds extends throughout the limestone belts. This thick limestone is followed by some 3,000 feet of grey, ashy beds, with intercalations of quartz-porphyries, one limestone band and two diabase sheets (see fig. 4).

This part of the section terminates with some grey, ashy beds, which are limited by green cleaved tuffs and lavas probably lying on the upthrow side of a fault. West of this fault the strike is between north and east, and the beds are very similar to the green rocks on Onder Plaats and Zonder Huis. The diabase at the west end of the section has not been sheared, and is similar to that at the east end.

There may be repetition of beds due to folding in this section,

but the dips from the porphyry on Groot Drink to the fault on Zwart Kop are all westerly and at high angles.

Veins filled with quartz and red felspar occur in the green rocks west of the fault.

Between the western diabase and the next succeeding rocks, the Koras quartz-porphyries, there is a conspicuous belt of white vein quartz, probably deposited along a fault.

Four isolated kopjes of dark magnetic cherty quartzite occur to the north of main area of the Wilgenhout Drift beds, and are separated from it by several miles of low ground, on which fragments and a very few outcrops of green slates were seen; these slates must certainly be placed in the Wilgenhout Drift series, but their relation to the magnetic quartzites is uncertain. In the case of two of the kopjes, the supposed Matsap beds of the Onder Plaats ridge intervene between them and the nearest outcrops of the Wilgenhout Drift beds. The quartzites are black, dark brown or grey, and they may be matched by specimens from either the Griqua Town or the Kraaipan formation; but no rocks which are decidedly peculiar to one of these two formations were found amongst the quartzites. No thinly-banded rocks were met with; they are all rather massively bedded rocks, in which the layers of different colour and magnetite contents alternate in thicknesses of an inch upwards. They dip between N.E. and E.N.E. The strike is thus parallel with the strike of some of the Wilgenhout Drift beds, but in an area of great disturbance, such as this is, parallelism or divergence of strike is not of great importance in grouping isolated outcrops. On the whole, the occurrence of the magnetic rocks would seem to lend weight to the view that the Wilgenhout Drift beds, supposing these to include the quartzites, belong to the Kraaipan formation.

About five miles north-east from the Upington beacon there is a low hill of dark quartzites, about 700 yards long and 300 wide, trending W. 40° N., with synclinal dips up to 50°. The quartzites are dark brown, red and rarely grey, and they usually have a uniform texture like the Zwart Kop rock, but they are thinner bedded, and include some gritty bands with a few quartz pebbles. Below the quartzites and on the south-west side of them there are a few small exposures of a fine grained blue diabase or epidiorite, whose relations to the surrounding beds could not be ascertained. Though these quartzites present some points of resemblance to the Zwart Modder series described below, they are here placed with the Wilgenhout Drift beds, because they lie above the diabase and are much more sharply folded than the Zwart Modder beds in this district. This isolated mass of quartzite and diabase occurs amongst the grey quartz and mica-schists of the Kheis series, to which they offer a marked contrast; they must in any case be of much later date than the Kheis beds and the intense metamorphism exhibited by the latter.

## THE ZWART MODDER SERIES.

North of Upington Common, as far as the Nossop, there is only one series of rocks intermediate in age between the Upington granite and the Karroo formation. These rocks are almost horizontal quartzites, sandstones, and shales, and they will for the present be called the Zwart Modder series, for they cannot be correlated definitely with any known formation. The outcrops of this series are separated from the nearest comparable rocks to the east by more than 100 miles of sand-covered ground, and the geology of the country south of the Orange River is too little known to allow a profitable comparison with the Ibiquas or the Nieuwerust series of Van Rhyn's Dorp and Calvinia. A comparison with the horizontally lying arenaceous beds of the Han Ami plateau[1] to the west, which have been referred to the Transvaal formation, does not aid us much, for the Zwart Modder group differs in many respects from the Transvaal formation as developed within Cape Colony.

The series consists of quartzites, sandstones, and shales, with a small amount of calcareous matter in them; no conglomerates were found, though the sandstones occasionally have a few isolated water-worn pebbles in them, but never in sufficient numbers to give rise to gravelly beds. The prevailing colour of the beds is red, though grey quartzites are occasionally seen, especially when the unconformable junction with the granite and schists is exposed, and again on a horizon about 500 feet above the base of the formation. Above this horizon the red beds become less frequent, and rather loose textured brown, yellow, or grey sandstones make up the bulk of the rock for a considerable thickness. What are probably the uppermost beds of this series seen during the last journey are blue-black shales with much detrital mica; the well-exposed beds of the Sannah's Poort hills probably lie below these dark shales, and they consist of thin sandstones and shales, red, pink, brown, grey, blue and green in colour.. Throughout the series both ripple-marked and current-bedded rocks occur and clay-pellets are scattered through many layers of sandstone and quartzite.

Towards the upper part of the series the rocks are very like some of the Karroo beds, and where there is no direct evidence of the position of distinctive Karroo rocks, such as the Dwyka, in the neighbourhood, it is difficult to be satisfied to which formation certain beds in isolated outcrops or wells belong; for very similar sandstones and shales occur in Gordonia both above and below the great unconformity at the base of the Karroo series.

Except near Sannah's Poort, where the rocks form the south-eastern limb of an anticline trending S. 35° W. into German territory, they lie nearly flat, with perhaps a dip of less than 1°

[1] Schenck, Pet. Mitt., 1888, 225. "Die Geologische Entwickelung Südafrikas."

towards the north or north-east. Their thickness must be considerable, though it is at present uncertain. More than 1,000 feet are seen in the south-eastern limb of the Sannah's Poort anticline, and there are quite 500 feet of beds, probably entirely below those of Sannah's Poort, between Ghous and Bloemfontein; then again more than 100 feet of yellow sandstones and blue shales, probably above the Sannah's Poort horizon, occur between Haakschein Vley and the Molopo. So that the exposed thickness is likely to be 1,600 feet. Then there must be some rock with south-easterly dip hidden between the easternmost outcrops of Sannah's Poort and the westernmost rocks of Haakschein Vley, a distance of some 12 miles, and the formation is cut off above by an unconformity. So the total thickness of arenaceous beds and shales in the Zwart Modder series is likely to be considerably more than 1,600 feet.

Some doubtful quartzites on the Upington Commonage, which I have placed in the Wilgenhout Drift beds, may possibly belong to this group, but for reasons given on another page (p. 42), they appear to belong to the older series.

The first outcrops of undoubted Zwart Modder beds were seen on the western side of Areachap, forming part of an inlier of granite and quartzite, surrounded by the Dwyka series. The granite forms a low kopje, and on the south side of it there are thin red quartzites and micaceous shales, dipping at moderate angles south-eastwards away from the granite. About 100 feet of these rocks are exposed before they are covered by the Dwyka boulders' beds. The quartzites contain a few well-rounded pebbles of vein quartz and many mud-pellets, and most of the layers are ripple marked. The junction with the granite is not seen at the surface, though outcrops of the two rocks lie within a few feet of each other. The junction is certainly an unconformity, and not an intrusive contact. A small area of quartzites, lying eastwards of a low granite kopje, occurs in an inlier on the south end of Rooi Puts surrounded by the Dwyka. A larger inlier has been uncovered by denudation on Steenkamps Puts and Blaauw Bosch; a small inlier of granite projects through the Zwart Modder beds. The quartzites here are grey, red and brown in colour, and contain numerous clay-pellets, the weathering out of which gives rise to pitted surfaces on the quartzites. There are also some red micaceous shales. These rocks lie nearly flat, and often show rippled surfaces. A second patch of quartzites on Blaauw Bosch wraps round the western end of a hill of granite, which projects into the Dwyka area here.

In none of these localities where the basal beds of the Zwart Modder series are exposed is there any evidence for the intrusive nature of the granite with regard to that group, and the same statement holds good in the case of the Ghous granite inlier, so there is no doubt that the Zwart Modder beds are of much later

age than the granite. Another noteworthy fact concerning these basal beds is that they do not include any arkose (consolidated granite debris); in this respect they differ from the basal beds of the Black Reef series, where these lie directly on granite in the Vryburg Division, and also from the basal beds of the Nieuwerust series lying on granite in Van Rhyn's Dorp.

A large area of Zwart Modder beds begins on Grond Neus, and stretches down a tributary of the Hygap and up the latter river to a point above Bloemfontein, where the rocks are covered by sand and surface limestone. The southern limit has not yet been traced, but from the position of an escarpment marked on a map issued with the report of the Anglo-German Boundary Commission,[1] the series evidently passes into German territory a few miles north of the Aries (M line) beacon, about in latitude 28° 4′ south. Though the boundary has not been mapped, granite hills on Small Visch and Toeslaan are visible from high ground on Ghous. On Ghous the base of the series is seen wrapping round the small inlier of granite and schists shown in fig. 1. The lowest beds are thin grey rippled quartzites. The dips seen round the older rocks are local, and perhaps to be accounted for by very slight earth-movements, which produced a more noticeable effect immediately about the then buried inlier than further away from the same mass of old rock.

The Zwart Modder beds are magnificently exposed in the valley of the Hygap between Bloemfontein and Ghous. They form cliffs on each side of the river, which here occupies a gorge, up to 200 feet high. Owing to the low northerly dip of the beds and the rise of the channel northwards, higher and higher beds are met with as one travels up the river. The beds on Ghous and Zwart Modder are chiefly thin reddish quartzites and red micaceous shales, much like some of the Witteberg beds of the south of the Colony. The quartzites often contain mud pellets. The alternation of thick bands of shales with quartzites or sandstone beds gives rise to terraced slopes where the cliffs become less steep than usual. Occasional coarse gritty quartzites occur on Zwart Modder. In the higher beds on Zwart Modder and Zout Puts the colour of the sandstones is less frequently red than below the Zwart Modder store; the rocks are more often grey or yellowish. The shales become of less importance above Zwart Modder, where thin-bedded sandstones, usually quartzitic on their exposed surfaces, form banks 50 feet thick. The thick sandstones are false-bedded, and have mud-pellets in them; ripple-marked surfaces are not frequent in this part of the series.

A thin section (1819) of a quartzite from Zwart Modder is seen under the microscope to be made of quartz, which is by far the most abundant constituent, clouded felspar without twinning, microcline and plagioclase, also a small amount of muscovite and zircon. Some of the quartz grains are well rounded, but there

[1] Berlin, 1906, plate II.

are many angular chips. Spaces between the grains are filled with quartz, often in optical continuity with one of the neighbouring quartz grains.

On Bloemfontein the Dwyka series covers much of the ground, but the Zwart Modder beds lie at a shallow depth, and are met with in the wells; they are seen at the surface on the eastern half of the farm, and again just south of the Kalk Vley beacon on the western side. The rocks are red and grey sandstones, grey quartzites and red micaceous shales; they lie almost flat.

North of Bloemfontein, I did not see any outcrops of this series nor wells sunk into it, until I reached the Skuynskalk pan (Uitzak); all the exposed rocks belonged to the Dwyka boulder beds, the shales above those beds, or to dolerite intrusions in them; but from information given to me by farmers, it is probable that there are inliers of the Zwart Modder beds on Naauwte, and perhaps on other farms along the German border.

There are two wells sunk in the Zwart Modder beds on the north side of the Skuynskalk pan, 40 and 97 feet deep respectively; the rocks thrown out are yellow and grey sandstones and blue micaceous shales, which have a dip of 5° towards south-east. These wells are entirely surrounded by superficial deposits, and I was for some time in doubt as to whether the rock belonged to the Karroo or Zwart Modder formation, but on the north side of the Skuynskalk dunes and about two miles from the wells, the Dwyka series is well developed, and the boulder beds lie at a level which is certainly some few feet above the top of the Skuynskalk wells. In this area of Karroo beds there is a considerable thickness of thin papery shale of a type which has not been found in the Zwart Modder series, and plant fossils, amongst which *Glossopteris* was recognisable, occur in these shales. The sandstones and shales of Skuynskalk very probably lie below the Dwyka, and they do not contain fossils. The next outcrops are on the north side of Koppjes Kraal pan, between it and Haakschein; they are grey sandstones and dark shales. Along the eastern side of these large pans there are several outcrops. The most extensive series of exposures is at the north-eastern side of Koppjes Kraal pan, where there is a line of cliffs (Blaauwkrantz), with a maximum height of about 100 feet. The cliffs show a succession of thick bands of almost black micaceous shale with interbedded layers of sandstone, 60 feet thick in all, capped by 40 feet of superficial sands and limestone. The shales contain a few dark calcareous concretions. I was doubtful whether these rocks might not belong to the Karroo formation, but a search lasting more than an hour failed to bring to light a trace of fossils, nor are there any boulders along the eastern edge of the pan at the level of the Dwyka boulder beds west of the pan. Though the Dwyka was not seen in place at the top of the cliff, nor in the sand-covered country just behind it, some boulders of blue amygdaloid and

several small pebbles of chalcedony from the amygdaloid were found in the surface deposits at the top of the cliff. It is likely that these typical constituents of the Dwyka boulder beds in this region come from a mass of those rocks lying above the beds seen in the cliffs and in the high-lying sand-covered ground east of them. On the whole, the evidence is quite in favour of the cliff section belonging to the Zwart Modder series. The outcrops on the east side of Haakschein Vley are greenish sandstones and shales of the Zwart Modder series; they are parts of a buried escarpment, continuous with the Blaauw Krantz cliffs. In many places, however, the steep sand hills east of the vley completely conceal these rocks. The sandstones contain occasional round pebbles of quartz and mud-pellets. The shales are thin sandy rocks like some of the Sannah's Poort shales. Similar sandstones and shales occasionally form flat outcrops on the floors of the Haakschein Vley and Koppjes Kraal pan, and they occupy large areas immediately beneath the floors of those pans, for intersecting straight lines of a slightly darker colour than the enclosed areas are seen on the hard, sandy mud. The dark lines are from 6 to 10 inches wide, and run W. 20° N and S. 10° W. on Koppjes Kraal pan, parallel to joints seen in flat outcrops in the same pan. The dark marks are due to the upward creep of moisture along the joints. I scraped away the hard mud from a few such places, and found the shale surface from one to five inches below.

For a distance of some 12 miles along the German boundary, in the neighbourhood of Sannah's Poort (near Rietfontein), there are low hills made of sandstones and shales, which must belong to the Zwart Modder series. They are chiefly thinly-bedded rocks, red, pink, brown, blue, and green in colour, dipping at various angles from 15° to 60° towards E. 35° S. Rippled surfaces and mud pellets are abundant in the sandstones. The axis of an anticline forms low ground in German territory, and the north-western limb lies about four miles west of Sannah's Poort. More than 1,000 feet of rocks are exposed in the south-eastern limb of the anticline in the Sannah's Poort hills. The junction with the Dwyka series is exposed on both sides of the stream bed which traverses the Sannah's Poort hills, and is continued towards Rietfontein. The uppermost of the lower group are hard thin green shales, much broken up at the surface. On each side of the stream the exact position of the unconformity soon becomes obscured by surface deposits, but for some yards on the banks the grey-blue Dwyka boulder beds are seen lying on the broken shales, which have a south-easterly dip of about 20°.

Thin sandstones and blue micaceous shales belonging to the Zwart Modder series have been thrown out from a dry well in the bed of the Hygap on Inkbosch Pan; and a low cliff of yellowish false-bedded sandstone on the left bank of the same river on Lieutenants Pan probably belongs to the same series.

No fossils of any kind were seen in the Zwart Modder series, though a considerable time was spent in looking for them in the favourable exposures.

In lithological character the Zwart Modder group does not resemble very closely any one formation which is well known in Cape Colony. In general appearance it often reminded me strongly of the Ibiquas series as seen behind Stinkfontein Poort in Calvinia, but that resemblance is due more to the horizontality of the beds and the alternation of harder and softer beds than to any very close lithological similarity between the two formations; in particular, no worm casts were seen in the Zwart Modder beds like those in the Ibiquas, and the latter are generally less micaceous than the former.

There is no special resemblance between the Zwart Modder and the Nieuwerust series, and the absence of arkoses from the basal layers of the former makes a definite dissimilarity between the two. Certain bluish quartzites, also, are rather characteristic of the Nieuwerust beds in Van Rhyn's Dorp, and nothing quite like them has been seen in the Zwart Modder beds.

The nearest outcrops of the Black Reef series are probably those on the Mashowing at Garaphoane, but they are not like the Zwart Modder beds. The latter are very much thicker than the former, and differ from them in colour and also in texture, especially in the lack of conglomerates. The presence of calcareous concretions in the shales of Blaauw Krantz may be thought to indicate the coming in of a limestone formation corresponding to the Campbell Rand series. If the Zwart Modder beds do belong to the Transvaal formation, a great change in its nature takes place between the Vryburg and Griqualand West area and the west of Gordonia. There is, of course, no reason why such a change should not have been brought about, but its assumption on our present information is hardly justifiable.

There is some resemblance to the Matsap series of the Langeberg, allowing for changes in the latter brought about by greater disturbance, due to earth-movements. The Lower Matsap beds, however, contain thin conglomerates not seen in the Zwart Modder group.

There can be very little doubt that the Zwart Modder series is part of the horizontally-lying formation which covers a vast area in German South-West Africa, including those parts of the central highlands of Namaqualand called the Huib, Han Ami, and Homs Plateaux. No complete account of the geology of that country has yet been given, but the writings of Schenck[1] and the more recent work of Schultze[2] contain valuable informa-

[1] Schenck, "Gebirgsbau und Bodengestaltung von Deutsch-Süd-West-Afrika." Verhandl., dis X., deutschen Geographentags in Stuttgart, 1903; also "Die Geologische Entwickelung Südafrikas," Pet. Mitt., 1898.

[2] Schultze, "Aus Namaland und Kalahari," Jena, 1907. See also Passarge "Die Kalahari," pp. 56 and 57, Berlin, 1904.

tion on the subject. The presence of dolomite or blue limestone on the top of the sandstones in the Huib and Homs Plateaux gave rise to the correlation with what is now called the Transvaal system, but more work will have to be done before that correlation can be accepted. In Schultze's book there are several good photographs ("Aus Namaland und Kalahari," pp. 149, 159, 555, Tap. VI. [Slangkop], VII. [lower figure]), of the horizontal sandstones, and they are evidently the same kind of rocks as those in the cliffs below Zwart Modder (a photograph of the Zwartputs [? Zoutputs between Zwart Modder and Bloemfontein] rock is given on p. 552 of the book). The descriptions of the rocks are in agreement with this view.

There is perhaps more reason to regard the Zwart Modder series as belonging to the Transvaal system than any other, but the evidence is not very strong yet. Very likely the survey of the country between Upington and Van Rhyn's Dorp will prove a correlation with one or other of the pre-Cape formations in the latter district,[1] or possibly with part of the Cape system.

Beyond furnishing good flagstones and in some places fencing poles, the Zwart Modder series has no economic importance. There are occasional small quartz veins, but nothing worth the attention of prospectors was seen.

## THE VAAL RIVER (VENTERSDORP) SYSTEM.

Rocks belonging to this system take a very small part in the structure of the area under description. The westerly termination of the belt below the Black Reef escarpment in the Motiton Reserve was described in last year's Report.[2] The further examination of the Mashowing valley below Motiton did not reveal more outcrops of the Pniel beds, though a small patch was found on the Morokwen Reserve. The Zoetlief beds form an outlier in the Motiton Reserve and Glenred, but were not seen elsewhere.

Between the outcrops of rocks belonging to this system in Vryburg and the country along the Orange River, where the lavas and sedimentary rocks of the Koras group occur, there is a wide stretch occupied by later and older beds. This fact, together with the lack of fossils in these formations, would alone make a certain correlation difficult, unless the lithological similarity were very close. The rocks here included under the Koras series differ from the hitherto described lavas and sediments of the Vaal River system in important respects, but there is some reason for thinking that the Koras series may have been formed

[1] After writing the above, I find a short description of the nearly horizontal beds in German S.W. Africa by H. Lotz, in Monatsbizichte d. D. Geol. Soc., Nos. 8/10, 1906, in which it is stated that the sediments of the Plateaux are (1) Arkose, slates and quartzites of little thickness; (2) dolomites; (3) sandstones and shales. It is the third group in this succession that is probably represented by the Zwart-Modder series.

[2] Ann. Rep. Geol. Comm. for 1906, p. 15, etc.

at about the same time as the Vaal River system, though their identity has not been established. In this Report, therefore, the Koras series will be placed as a distinct sub-group in the Vaal River system.

## THE ZOETLIEF SERIES.

Though quartz-porphyries and some compact fine-grained flaggy beds referable to this series undoubtedly form a considerable outlier on the bult between the Glenred laagte and the main valley of the Mashowing, the rocks are rarely exposed. They crop out occasionally from under the pale-coloured sand which covers the rocks over so large an area in the north of Vryburg and Kuruman. The outcrops are chiefly on the slopes of the bult, though sufficient fragments occur on the surface of the bult to satisfy one that there probably is a continuous outlier several square miles in extent. Near Mathioane some fine-grained grey flags crop out, and above them lie quartz-porphyries, pink in colour. About three miles north of the store at Takoon, at the extreme southern end of the outlier, there are greyish pink quartz-porphyries. A thin section (1843) from one of these outcrops shows the rounded remnants of a few quartz crystals, which have been partially resorbed by the rest of the rock when it was fluid; the bulk of the rock consists of quartz and felspar, which interlock and enclose smaller indeterminable constituents. The felspar is crowded with decomposition products.

In the last Annual Report[1] a description was given of some outcrops of the Zoetlief beds on the farms Hartebeest Pan, Kaffir Pan, Klipfontein, and Schildpad Kuil, in Vryburg, but no thin sections of the rocks were then available. Three slices have been cut since then; two of them are from the Kaffir Pan rock. These (1634, 1635) show porphyritic crystals of quartz and felspars rounded, and, in the case of quartz, deeply corroded by the magma and containing patches of it. The felspar is partly orthoclase, but most of it is plagioclase of a variety near oligoclase. There are also a few pseudomorphs of chlorite and quartz mosaic after a ferro-magnesian constituent, possibly a pyroxene; those are also zircons and altered ilmenite; a small amount of epidote and calcite are present. The ground mass is a microcrystalline mixture of quartz and felspar.

The slice (1636) from a specimen from Schildpad Kuil shows rounded and corroded crystals of quartz and felspar in a peculiar matrix, which looks like that of the Kaffir Pan rock by ordinary light, but between crossed Nicols it breaks up into large interlocking areas of quartz and perhaps also felspar, enclosing indeterminable dusty specks. The quartzes are cracked, and sericite fills some of the cracks, which do not extend into the matrix, except in two cases of cracks filled with quartz mosaic

[1] Ann. Rep. Geol. Comm. for 1906, pp. 14 and 15.

and a yellowish substance. The felspars are considerably altered, but enough of the original minerals are left to show that they include untwinned and repeatedly twinned felspars. Calcite and sericite are present as alteration products. There are a few small patches of chlorite, without such definite form as in the Kaffir Pan rock. Some calcite is found in the ground mass.

## THE PNIEL SERIES.

The country in which the Morokwen Reserve lies is mostly covered with surface limestone and sand, but sufficient outcrops were found to indicate the approximate positions of the boundaries between the Campbell Rand series and the Black Reef, and also between the latter and the westernmost granite of the south-eastern part of the Reserve. Between the Black Reef outcrops near the Cattle Post north-east of Karathiuse and the granite there are outcrops and loose lumps of blue amygdaloidal lava and of greenish flags that prove the occurrence here of a patch of the Pniel series, for they are like typical rocks of that series further south-east. The extent of the Pniel series in Morokwen has not been proved, but it cannot be very great.

The Pniel beds between Takoon and the neighbourhood of Vryburg were described in last year's Report,[1] but thin sections of the rocks were not then available. A few sections have now been cut and examined, and will be described here.

An amygdaloidal lava (1628) from the hill covered with native-built schanzes in the fork of the Mashowing, just west of Takoon (Ann. Rep. for 1906, p. 16) is a rock of the augite-andesite class. Porphyritic crystals of felspar and augite are set in a matrix of small felspars and interstitial, almost glassy, matter. The large felspars have been replaced by chlorite, calcite, and sericite. The augite is generally fresh; it is colourless, and usually in long sections; the cross-sections show both prisms and pinacoid faces or the latter alone; occasional twins on (100) are seen; there are also shorter crystals with end faces. There seems to be no augite in the ground mass. The ground mass consists of small felspars, often in twins, a variety near andesine, a small amount of quartz, magnetite, and chlorite, calcite, and epidote as obviously secondary products; there is also an obscure weakly polarizing substance, brown with dusty inclusions, taking the place of original glass. The amygdales are made of layers of chalcedony, calcite, chlorite, and an opaque earthy substance.

A section has been cut from a compact-looking blue "diabase" forming the Takoon beacon hill (Ann. Rep. for 1906, p. 17), the intrusive or volcanic character of which was not determined. The slice (1631) shows much colourless augite in large plates, often with crystalline boundaries, set in a ground mass of

[1] Ann. Rep. Geol. Comm. for 1906, pp. 15—19.

plagioclase, some augite, a little quartz, magnetite and ilmenite, and as alteration products epidote, calcite, and chlorite. The augite is often twinned on (100); the faces most often seen are prisms and pinacoids, but in some transverse sections only pinacoids are noticed; end faces are sometimes developed; the augite has a striation parallel to the base in some sections. There are a few large felspars, irregularly shaped and partly altered; they are not so frequent as in the schanz hill rock. The small felspars belong to the oligoclase-andesine group. The ground mass contains little or nothing that can be referred to glass or its alteration products. No amygdales are seen in this rock.

A slice (1629) cut from the intrusive rock between the Black Reef quartzite and the granite south of Takoon (Ann. Rep. for 1906, pp. 16-17) presents some peculiar features. It is a dioritic rock with much micropegmatite. Hornblende is present in abundant large often ill-defined plates, sometimes penetrated by felspars; it is partly bounded by crystal faces, prisms and pinacoids, and it is often twinned on (100); it is strongly pleochroic (X pale yellowish Y rather bright green, Z blue green). The felspar is much decomposed, but an acid plagioclase, with refractive index less than that of quartz, is visible, and there is also untwinned felspar, presumably orthoclase, forming micropegmatite with quartz; micropegmatite forms a large part of the ground mass. Magnetite and ilmenite are present, and also chlorite, epidote, and calcite, as alteration products.

An amygdaloidal lava from Harbro (1633) contains no large porphyritic constituents. The amygdales are of quartz and chlorite; they lie in a fine-grained matrix of small felspars, quartz, magnetite, chlorite, and opaque dusty matter. The felspar is only partly unaltered, often in single twins with low extinction angles. The quartz is in small interstitial patches. The chlorite is in small patches, many of which evidently represent original grains of augite, for some have the octagonal shape of augite sections bounded by prisms and pinacoids; in some cases they are surrounded by minute opaque grains, probably magnetite. Chlorite also forms very slight plates, giving short needle-shaped sections.

## The Koras Series.

This name is proposed for some quartz-porphyries, amygdaloids of more basic composition, conglomerates and sandstones seen on the right bank of the Orange River above Upington. The greater part of the conglomerates and sandstones is of later date than the igneous rocks, for fragments of the latter are the most conspicuous constituents of the conglomerates, but in some places there are fragmental rocks similar in character to the later ones interbedded with the lavas. These rocks taken together form a group distinct from all others in the district; they are all red or purple in colour, and nothing quite like them is known

to me from any other part of the Colony. Though there are certainly two or more unconformities within this series, the members of it seem to be so closely related that it would at present introduce unnecessary complication to divide the group up into formal sub-divisions.

So far as the examination of the Koras series has yet been carried, the lowest rocks in it are either quartz-porphyries or amygdaloidal lavas of more basic composition, and fragmental rocks of the nature of tuffs made of fragments of the amygdaloidal lava. The conglomerates and sandstones lie above these igneous rocks.

The series occurs in two rather large areas and two smaller ones. The largest area extends from Leeuw Draai on the east, where it is probably faulted down against the Wilgenhout Drift beds, and Koras-Uizip-Kameel Poort on the west, where it is faulted down against the Kheis beds. The distance between these faults is about 14 miles in a straight line measured near the Orange River, but as the eastern fault trends a few degrees east or north and the western one about north-west the area occupied by the Koras beds widens northwards, where it is buried under the red Kalahari sand. Along both boundary faults there are masses of a rock called diabase in the field, but which proved to be a doleritic rock, with some altered rhombic pyroxene and much devitrified glassy base; both intrusions are very similar rocks to that forming the Groot Drink mass, which also occurs along a fault (see p. 36).

The other large area is that of Rooi Kopjes, Rouxville and Uap, where there are amygdaloidal lavas resting unconformably, and apparently but little disturbed, upon the Kheis beds. Two small outliers were seen on the Kheis beds on the southern corner of Koras and on Rouxville.

On the farm Leeuw Draai a wedge-shaped strip of porphyry and amygdaloid, about a mile wide near the river, and thinning out towards north-north-east, separates the mass of intrusive dolerite mentioned above from the conglomerates and sandstones seen on Albany and also on Leeuw Draai. The disappearance of the igneous rocks towards the north is partly due to their having been cut out by the fault, for their strike is generally north-east, while the fault trends nearly north; there is also an unconformity above them, and this certainly contributes to their disappearance at the present surface.

The porphyry is a red rock containing crystals of felspar, quartz and a pegmatitic intergrowth of the two. Under the microscope the matrix (1846) is seen to consist of rather large irregularly-interlocking areas of quartz and felspar, crowded with dusty reddish matter, which evidently gives the characteristic colour to the rock, and a few flakes and grains of chlorite and epidote. The quartzes are chiefly well rounded and sometimes deeply corroded, but they occasionally have traces of crystal faces; the larger individuals are cracked, and the cracks,

which do not extend into the matrix, are filled with calcite. The felspars are similarly corroded; they are orthoclase in carlsbad twins, alone or intergrown with quartz; there is also a twinned plagioclase of a kind near oligoclase. There are also pseudomorphs of chlorite and epidote after a pyroxene which had more perfect shape than the other minerals. These pseudomorphs, which are of smaller size than the quartz and felspars, are often grouped together with magnetite and apatite. The rounded pegmatites are as much as an inch in diameter. and, in conjunction with the general appearance of the rock, distinguish it at a glance from any other quartz-porphyries known in Cape Colony

On Leeuw Draai this porphyry occurs in layers several feet thick, interbedded with the amygdaloidal lava, dipping north-westwards under the Albany conglomerates. The amygdaloid is a red or purplish rock with many amygdales of quartz and epidote. There are no porphyritic constituents, though the larger felspars reach the length of half a millimetre. The felspars (1786) are quite fresh, in lath-shaped sections, and have symmetrical extinction angles up to 18° or 20°, so they are of a composition between andesine and labradorite. The base in which they lie is a devitrified glass containing magnetite crystals, arranged in intersecting lines like skeleton crystals, and grains of a rather highly refringent and bi-refringent mineral which is probably epidote. There seems to be a little quartz, but most of the glass has given rise to aggregates of weakly refracting minerals of uncertain nature. There is enough haematite to colour the rock red, seen in thin sections clustering round the felspars. No pyroxene or recognisable pseudomorphs after it or another ferromagnesian mineral were seen. There are layers of red agglomerate and fine-grained tuffs interbedded with these lavas, and they contain abundant fragments of the amygdaloid.

No further outcrops of the amygdaloidal lavas were met with between Leeuw Draai and Kameel Poort or Koras, but quartz-porphyries form two very prominent kopjes projecting from the sand on Koras, about eight miles from the river, and from these kopjes three other similar hills are visible towards the north-east from two to six miles distant, but these were not visited. The rock is of essentially the same nature as the Leeuw Draai porphyry. A thin section (1787) shows that it is made of two kinds of rock, the major part is a porphyry quite like that of Leeuw Draai, with, however, some zircon crystals in addition to the constituents seen in that rock; this contains irregularly-shaped rounded masses and elongated streaks of a darker material made of precisely similar minerals as the other, but the quartz and felspar occur in chips, small fragments of crystals with sharp edges; the matrix of the darker rock is rather finer grained and contains more of the red, dusty matter than that of the rest of the rock. No amygdaloidal lava nor sedimentary beds were found either on or in the immediate

neighbourhood of the kopjes. Though one of the hills rises about 150 feet from the sand, no divisional planes that could be looked upon as separating distinct lava flows were found; the rock seemed to be uniform throughout, and it is traversed by regularly placed joints which have allowed the rock to weather into huge rounded blocks that ring like metal when struck. The kopjes look as if they were made of boulders not less than six feet in diameter piled together. The debris from the weathered rock between the blocks has usually been removed by wind and rain, and as far as I could creep between the boulders into the hill no rock undoubtedly *in situ* was to be seen. The general aspect of these hills is exactly like that of the granite "tors" on Upington Common, described on a previous page.

Though no definite evidence of the intrusive nature of the quartz-porphyries on Leeuw Draai was obtained, the appearance of the rock there, and especially in the Koras kopjes, would indicate that it is intrusive.

The nearest exposed rocks in the neighbourhood of the kopjes are red sandstones seen about a mile to the south, dipping 45° to S. 10° W.

The conglomerates and sandstones cover an almost continuous area, 14 miles in length, between Leeuw Draai and the fault on Koras and Uizip. Towards the north they are covered by the red Kalahari sand, which extends in the form of long dunes to the river at several places; an especially broad strip of dunes is found at Kalk Punt.

These beds lie unconformably upon the lavas of Leeuw Draai. They are very frequently exposed for short distances, but their dips vary greatly in direction and amount. Dips as high as 50° were recorded, but they are usually lower than 20°, and they are most often towards the north, between north-north-west and north-east.

The sandstones are dark red rocks, often rather loose in texture, but they include many quartzitic layers. They are as a rule obviously felspathic, and, from the abundance of pebbles of the red porphyry and amygdaloid throughout the conglomerates, and of reddish granite and gneiss in some parts, it is evident that a large part of the sandstones and conglomerates was derived from such rocks. The conglomerates occur throughout the sedimentary part of the Koras series; in places they were seen to form lenticular beds a few feet thick and 100 yards or less in length along the outcrop. In many bands the matrix is soft, so the boulders and pebbles have weathered out and cover the ground over wide areas just as in the case of the Enon boulder beds in the south of the Colony. The pebbles are of all sizes up to two feet in length, and are almost always well rounded. Many of them are fractured, either along parallel planes or radially about a small indentation caused

g stone. The segments of frac-
slightly relatively to each other.
depressions, not connected with
surface of some of the pebbles,
bles in the Pokwani conglomer-

ebbles are red quartz-porphyry,
hitish quartzite, granite, gneiss,
vein quartz. A careful search
f blue or green slates or lava,
y or magnetic and red quartzite,
m the Wilgenhout Drift series.
les became more abundant than
he area, though even in the west
as the quartz-porphyries. There
conglomerates with pebbles not
ameter. In many of these con-
ders are closely packed.
andstones is the almost complete
n in the thicker layers.
Koras, the sandstones and con-
lened, and, as a rule, darker in
from specimens taken from dis-
om the dolerite outcrops. The
ous rock consists (1788) of many
of detrital origin, embedded in
als, quartz, epidote, and calcite.
e clear angular or sub-angular
inerals are mostly crowded with
ere is some clear chalcedonic or
ce comes from a spot about 20
789) shows clear quartz grains
oudy quartz in optical continuity
is in much larger grains than
ss inclusions. The rock consists
onstituents, the only other con-
and reddish substances. The
ithin 10 yards of the intrusion;
epidote is frequently in crystals.
a mass of grit enclosed by the
e quartz and oligoclase grit with
and quartz. The oligoclase is
has not suffered any appreciable
of quartz-mosaic. At the junc-
entary rocks there is much fine-
ock (1795) of uncertain origin,
rock are seen within the sedi-

m. for 1906, p. 100.

mentaries of more usual character; the epidote rock may be an altered sediment.

On Kameel Poort there is a small mass of amygdaloid lying in a deep hollow near the north-eastern end of the Uizip beacon hills which are made of Kheis beds. Whether it is continuous with the large outlier to the west round the north end of the hills is uncertain as the ground is covered with superficial deposits. The amygdaloid lies near a steep wall of quartzite on the south-west, and is separated from it by a fine-grained siliceous and epidotic altered rock, probably an altered part of the lava, and by a few feet of breccia of quartzite fragments from the wall rock in a red siliceous base. The amygdaloid (1797) at this locality is like that of Leeuw Draai. The amygdales are of chalcedonic silica, epidote and chlorite, and they lie in an originally glassy matrix crowded with fresh felspars of the andesine group and small masses of magnetite, and also crystals of magnetite arranged in rectilinear intersecting rows; the base is almost opaque owing to the amount of red dusty inclusions and occasional transparent red flakes of haematite. No augite or other ferromagnesian mineral is present, but there are grains of epidote in the matrix. There are also patches of chalcedonic silica taking the place of some of the usual brown base in the interstices between the felspars. The hard siliceous rock between the amygdaloid and the quartzite (1798) shows no structure like that of the amygdaloid; it is made entirely of quartz, epidote, and calcite. The most of the quartz is in very small veins traversing a granular aggregate of the other minerals. The ordinary colourless and yellow pleochroic epidote often forms crystals projecting into the quartz veins. Much of the epidote is a peculiar variety which has not been seen in the other epidotic rocks of this district; it is a pleochroic pink mineral like piedmontite (X colourless to bright yellow, Y pink, Z deep pink). There is also some magnetite and much dusty opaque red matter, which gives the rock its colour as seen in mass.

It seemed to me that the Kameel Poort outcrops may mark the position of a vent, whence some of the volcanic rocks were ejected.

The large outlier covers about 10 square miles and passes under sand to the north-east. It lies in a wide hollow in the Kheis beds. The peculiar appearance of the well-rounded hills, in marked contrast to the sharper outlines of the hills made of the Kheis quartz-schists, has given the name Rooi Kopjes to one of the farms on which they occur. No fragmental rocks were seen in this outlier, and only very obscure divisional planes could be seen in the lava, the total thickness of which must be over 200 feet. Two slices were cut from the lava on Rooi Kopjes. One of them (1800) shows an almost opaque red ground mass, evidently once a glassy base similar to that of the Leeuw Draai rock, crowded with felspars of the andesine

series, of which some only are still fresh, and containing a few pseudomorphs of epidote and a serpentinous mineral, probably after a rhombic pyroxene. The other slice (1799) is from a rock of similar type but greatly altered by the conversion of all the felspars into aggregates of quartz and epidote; this slice shows more of the pseudomorphs after the supposed pyroxene; remains of the rectilinear groups of magnetite crystals are seen in the once glassy base. The amygdales in both these specimens are of epidote and quartz.

The rocks of this inlier seemed to be more generally epidotised than the Leeuw Draai lavas, and they have a very conspicuous and characteristic appearance owing to the abundance of bright green amygdales in a deep red or purple matrix; the purple colour is evidently due to the close intermingling of the red iron oxide and yellow or green epidote in the rock.

It will have been seen from the foregoing description that the Koras beds differ considerably from the known rocks of the Vaal River system. Their field relations to the Kheis beds are clear, the latter are very much older than the former, which rest upon them. It is also very probable that the Koras beds are much younger than the Wilgenhout Drift beds. If the suppositions, first, that the Koras beds belong to the Vaal River or Ventersdorp system, and, secondly, that the rocks of the Groot Drink hills are of Matsap age, are correct, the disparity between the changes in them wrought by pressure and earth-movements has to be explained. It may be that the down-faulted Koras beds lay just beyond the western limit reached by those changes. On the other hand, there is no good reason for excluding the possibility that the Koras series may be of later age than the Matsap beds and the movements that affected them. That the Koras series is of pre-Karroo age is extremely probable, for the Karroo rocks in that region, so far as known, have not been disturbed so much as the Koras beds. It cannot yet be said that fragments of the Koras beds are known from the Dwyka conglomerate.

## The Transvaal System.

Rocks belonging to this system have not been definitely recognised west of the Langeberg-Korannaberg range. The view expressed by Penning[1] that these rocks should reappear in the Kalahari has not been confirmed in the southern part of that region; at the same time there is room for the occurrence of one or more members of the system under the sand south of the Molopo, and, as noticed previously, it may be the case that the system is partly represented by the Zwart Modder series.

---

[1] Penning, gold and diamonds, London, 1901. Also in Wilkinson's "Notes on a Portion of the Kalahari," Geographical Journal, 1893.

### *The Black Reef Series.*

This group was followed from the neighbourhood of Takoon down the left side of the Mashowing, where it is largely hidden under sand, and across the river at Garaphoane, where it is again concealed by sand. It was seen again on the Morokwen Reserve.

South of Motiton, the Tong Valley fault, which has a north-westerly course, displaces the beds so that on the upthrow (north-east) side they stretch at the surface much further south, owing to their low dip, than on the south-western, or downthrow side.

For a distance of some 12 miles between Zwart Fontein and Geluk there are some beds of a type not usually met with in the Black Reef series lying nearly at the top of it. They are ferruginous clayey sandstones and shales and cherty rocks, yellow and brown in colour, containing some magnetite. They give rise to a belt of rising ground called the Zwart Rand. They are probably about 80 feet thick. The cherty rocks are very like the more massive jaspery rocks of the Griqua Town series. It is possible that the fragments of magnetite quartzites found behind the Black Reef escarpment on Clapham, referred to on a previous page as possibly indicating an inlier of the Kraaipan series, may belong to a similar band to the Zwart Rand beds; but the fact that they occur in a depression is rather against this view. Similar rocks were not found in a corresponding position south of Motiton and Takoon, nor have they been recorded from the Black Reef series nearer Vryburg.

The Takwanen inlier, mentioned in last year's Report,[1] is an oval area of quartzites, thin dolomitic limestones and some volcanic rocks. The Lochnagar fault and dyke traverse its longer axis, but die out north of the Takwanen boundary. The inlier is thus a faulted anticline. The dips are very low, which makes the small thickness of beds involved occupy a rather large area. The lavas and tuffs all belong to the volcanic rocks lying near the top of the Black Reef series on the Vryburg escarpment. The lavas of the Pniel group at the base of this escarpment are not brought to the surface in the inlier.

A section seen along the river through Takwanen gave the following figures:—

| | |
|---|---|
| Campbell Rand series at the top. | |
| Blue amygdaloidal lavas and blue-green flaggy tuffs, | 15 ft. |
| Blue dolomitic limestone, | 8 ft. |
| Blue amygdaloid and flaggy beds, | 30 ft. |
| Blue dolomite, | 5 ft. |
| Flaggy beds passing below into grey quartzites and grits, the usual type of quartzite of the Black Reef series in this neighbourhood, | 50 ft. seen. |

[1] Ann. Rep. Geol. Comm. for 1906, pp. 22—23.

The flaggy beds in this section are strongly ripple-marked.

On Garaphoane the series is exposed on each side of the Mashowing for a short distance. It there consists of quartzites and conglomerates. The pebbles are chiefly of quartz, but banded black and white cherts, green chloritic rocks, quartzites, dark slates, and some schistose magnetic rocks occur. The quartzites are false-bedded, and ripple-marked surfaces are often seen. They dip westward at low angles.

On Morokwen the series is poorly exposed, but the outcrops and a slight rise marking their position are sufficient to show that the Black Reef beds trend north-eastwards through the Reserve.

## *The Campbell Rand Series.*

The Kaap Plateau, which is made almost entirely of these rocks, was crossed between Vryburg and Takoon; nothing of particular importance was met with, no fossils were found in the rocks. On Armoed's Vlakte near Vryburg a rather peculiar looking rock was seen above the highest beds that could be placed in the Black Reef series. It is a gritty rock, which weathers with a brown scoriaceous-looking surface; in thin section (1713) it is seen to be a gritty rock, with much calcite or dolomite. The gritty constituents are chiefly quartz, but there are also fragments of felspar and a few small pieces of a felspathic igneous rock that may have come from the Pniel lavas or intrusive sheets associated with them. Deposition of quartz has taken place round many of the quartz grains, and there is also some chalcedonic silica. The carbonates form grains and rhombohedral crystals in the rock matrix, and also oolitic grains, of which the original concentric structure is usually only visible by ordinary light, owing to its partial obliteration by subsequent crystallization of the carbonates.

The plateau formed by this series is about 62 miles wide near Kuruman, but decreases to 24 miles west of Garaphoane, where it is crossed by the Mashowing. Northwards it maintains about the same width as far as Morokwen. Penning evidently noticed this fact, and attributed it to the thinning out northwards of the dolomites.[1] No definite evidence for this statement has been brought forward, and the rocks are so much concealed throughout the area that in the absence of deep bore-holes the facts are difficult, if not impossible, to obtain. The dips are everywhere low, and there may well be undetected faults and gentle folds which greatly increase the width of country occupied by this group in the plateau.

The dolomites and cherts are only seen along the Mashowing for a distance of about half a mile some four miles up the river from Piet Quane (Derwent on the Divisional maps). The rocks

[1] Penning, quoted in Wilkinson's paper cited above.

are blue crystalline dolomites, with a few chert bands in them, very like many outcrops between the Mashowing and the Orange River. North of the Mashowing no outcrops were seen near the road between Heuning Vley and Morokwen; sand and surface limestone cover the rocks completely. South of the Mashowing no outcrops were seen within five miles of the hills formed by the Griqua Town series for some 15 miles south of Piet Quane, but the dolomites and cherts appear frequently on Kooroon and Gamolilo, and further away from the hills on Foster and Padstow.

West of the Kuruman hills in this region outcrops are exceedingly scarce, and there was no evidence found to indicate the extension of the Maremane anticline as far northwards as the Kuruman River.

In the middle of the scattered ranges known collectively as the Korannaberg there is a ridge, about four miles east-north-east of the watering-place called Blaauw Krantz, made of a mass of Griqua Town beds occupying the axis of an overturned anticline in the Matsap series. On the east side of the ridge, in a small kloof, there is a much broken but thick band of dolomite, which seems to dip at high angles westwards under the Griqua Town beds. It is a blue and grey rock generally, but there are reddish streaks in it, and also some dark cherts. This is the most westerly outcrop of the Campbell Rand series yet seen in Bechuanaland.

## THE GRIQUA TOWN SERIES.

In this district the Griqua Town beds were only seen in the Kuruman-Heuning Vley hills and the country to the west of them.

### *(a) The Lower Griqua Town Beds.*

These rocks form the Kuruman-Heuning Vley hills, an escarpment rising from the Kaap Plateau and limiting it on the west. For some 12 miles south of the gap cut by the Kuruman River the hills trend north-west, but between the Kuruman and Mashowing Rivers the trend is about N. 10° W. North of the Mashowing the rocks are very little exposed for some distance, but the position of the low hills made by the Lower Griqua Town beds on Dutton indicate a nearly northerly strike. North of the gap by which the conjoined Kgogole and Mokgalo laagtes pass through the belt of Lower Griqua Town beds, the general trend of the latter and of the hills formed by them is about north-north-east past Heuning Vley. I was on the hills some four miles north of Heuning Vley, and they are continued in a group of low hills for several miles further towards the north-north-east, then they apparently break off and reappear again at Skelek.

The dips are everywhere low, and are directed chiefly towards

the west. Near Heuning Vley, where the exposures are better than usual, low anticlinal flexures with axes at right angles to the trend of the hill are seen on the eastern slope of the escarpment; their effect is to give a slightly-arched shape to the beds outcropping on a long uniform piece of the slope. At the base of the escarpment at Heuning Vley, where it forms several low krantzes rising immediately from the floor of the pan to a height of 20 feet or less, there are some rather sharp corrugations affecting small thicknesses of rock. These are very similar to the less pronounced of the disturbances seen at the base of the Lower Griqua Town beds further south,[1] and they probably may be attributed to a similar cause, viz., the solution of the underlying limestone and dolomite and the settling down of the base of the Griqua Town beds No outcrops of the Campbell Rand beds were seen near Heuning Vley, but from the sudden change in the topography at the base of the escarpment and the abundance of surface limestone on the low ground below it, there can be little doubt that the boundary between the Griqua Town beds and the dolomites nearly coincides with the eastern boundary of the escarpment.

On the Kuruman River the Lower Griqua Town beds do not appear at the surface within a mile or more of the bed where it goes through the hills below Tsenin. South of the river the height of the hills decreases considerably near Gamopedi; north of the river they rise gradually and make a low rounded range, which extends to Bromley, with very few small krantzes on its eastern side; near Bromley it disappears under the sand. The Heuning Vley hills rise some 600 feet above the floor of the Vley; the kloofs on their eastern side have small krantzes and rock-shelters, but not such large ones as are found south of Kuruman in the same range.

In lithological character the beds north of Tsenin are very like those to the south, in the Asbestos-Kuruman range, described in the Annual Reports for 1905-6. The greater part of the rocks exposed on the hills is a thin-bedded ferruginous chert or jasper, often with much magnetite; it is most often brown, but red and yellow jaspers are also seen.

The top of the Lower Griqua Town beds is buried under superficial deposits just below Tsenin, but it is exposed further down the Kuruman River, about three miles above Upper Dikgathlon, where an anticline brings the Lower Griqua Town beds to the surface again for a short distance. The rocks are not well exposed, but on the right bank of the river the uppermost three feet of the glacial beds are exposed. There is room for a considerable thickness of these beds east of their outcrops before the highest westerly dipping brown and black banded jaspers are seen; they are on the western limb of the anticline; on the

---

[1] Ann. Rep. Geol. Comm. for 1905, pp. 166, 168.
Ann. Rep. Geol. Comm. for 1906, pp. 35-36.

eastern limb they are hidden. The rocks are dark coloured siliceous beds without lamination, and they contain pebbles of black or grey chert scattered through the matrix at rather wide intervals. Two scratched pebbles were found. These beds are very like the glacial beds at Punt in Griqualand West. Beyond the proof they give of the occurrence of this horizon and the glaciated pebbles on the Kuruman River, the most interesting point in connection with these outcrops is that they are immediately overlain by the lavas of the Middle Griqua Town or Ongeluk group. There are thus apparently no representatives of the 12 to 30 feet of laminated hard shales at the top of the Lower Griqua Town beds, such as are seen at Juanana, Punt, Monjana Mabedi, and other places further south.

The glacial beds occur again in the Madebing laagte, about nine miles above its junction with the Mashowing. Owing to my having been obliged to travel through this neighbourhood by night, I could not examine the occurrence properly, but outcrops of the glacial beds were found on the slope of the laagte near the drift by which the Madebing-Heuning Vley road crosses the laagte. On the Mashowing this horizon is not exposed, nor was it seen anywhere along the western foot of the Heuning Vley hills.

### *The Black Rock.*

About seven miles from Upper Dikgathlon on the road to Korannaberg there is a remarkable black kopje projecting from the sand to a height of some 80 feet. From the top of the hill, which is a very well-known landmark, one can see the Korannaberg and the Kuruman hills, but it is separated from the nearest outcrops to the south, on the Kathu beacon hill, by 40 miles of sandy ground, and there are no outcrops directly north of it within the limits of the Colony. The hill is called the Black Rock, it is about 400 yards long and 150 wide. It is chiefly made of hard black, red, and brown jaspers, containing much magnetite, and some softer layers contain manganese. The eastern part of the hill is made of rather massive black beds, with a few bands of bright red rock; the western part is of thinner-bedded brown and black rock. The dip of the beds is towards W. 15° S., at about 25°, but the beds are often crumpled on a small scale.

Beyond saying that the lithological characters of the rocks would perhaps place them in the Lower Griqua Town beds, there is nothing definite to decide the horizon to which they belong. They may, however, belong to the Upper Griqua Town beds. The rocks for many miles on all sides of the hill are hidden, so that until further information is got from wells, it is useless speculating as to the evidence afforded by these outcrops on the northern course of the Maremane anticline and the Paling fault.

### (b) *The Middle Griqua Town or Ongeluk Beds.*

These beds were seen in two localities only, on the Kuruman River below Tsenin and near Madebing, but there is no doubt that they occupy a wide area immediately west of the Kuruman-Heuning Vley hills, where they are covered by sand. There is an uncertainty as to the structure here, but it seems likely that the anticlinal fold that brings in the Lower Griqua Town beds at Kathu Forest, *i.e.*, the Maremane anticline, dies out not far from Kathu, and that the Middle group underlies most of the sand between the Kuruman hills and the Black Rock on the Dikgathlon-Korannaberg road.

The lavas of the Ongeluk group are first met with about two miles down the Kuruman River, below the confluence of the Matlowing. A very small distance is available here for the Lower Griqua Town group, but as there are no outcrops within a mile or so of the river, it is quite uncertain whether there is a fault with downthrow to the east in this neighbourhood, or whether the dip of the Lower beds becomes steeper than usual here. One of those suppositions seems necessary to account for the narrowness of the belt available for the latter beds.

The lowest lavas seen are green amygdaloidal rocks with numerous amygdales of quartz, chalcedony, calcite, and pyrites. A thin section (1733) shows a devitrified glass matrix, now represented by a mixture of, probably, quartz, chlorite, calcite and a little epidote, and crowded with radiating bunches of very narrow felspars and scattered elongated thin ill-defined prisms and grains of augite, together with very small crystals of magnetite. The felspars belong to the oligoclase-andesine series and are fresh.

Another mass of lava near the last has rather different characters. A thin section (1735) shows that it was originally a glassy rock, but the glass is now represented by a mixture of minerals, including some epidote and much semi-opaque whitish matter; it is crowded with very small fresh felspars, giving symmetrical extinctions about the twin planes up to 8°; augite is not plentiful, but it occurs in grains between the felspars. There is a fair amount of quartz in the matrix. The amygdales are of quartz and chalcedony with opaque whitish aggregates and some radiating bundles of extremely fine needles, which do not affect polarized light, and to which red dusty particles are attached.

The next rock seen is either a more compact lava or an intrusion. A thin section (1734) shows that the rock has been considerably altered; it consists of rather large and irregularly shaped sub-ophitic augite, crowded with dusty inclusions, and rarely showing traces of a crystal face. The felspar is in large and small, often ill-developed crystals, usually altered to epidote, chlorite, and an aggregate of colourless minerals; it is not often twinned, but the inside part, preserving the shape of a crystal, is

frequently sharply distinguished from a fresh outer zone by its more advanced alteration. There is some quartz in small patches in the matrix, which also contains very much epidote and chlorite.

There is a fairly continuous succession of outcrops for some four miles along the river near Gasese. Much of the lava seems to be like that described above, but there are other varieties. A dark green rock with small black specks in it resembles some of the lavas seen in all the Ongeluk areas further south. Under the microscope (slice 1736) it is seen to have a matrix of a felted mass of microlites or very slightly-developed long crystals of

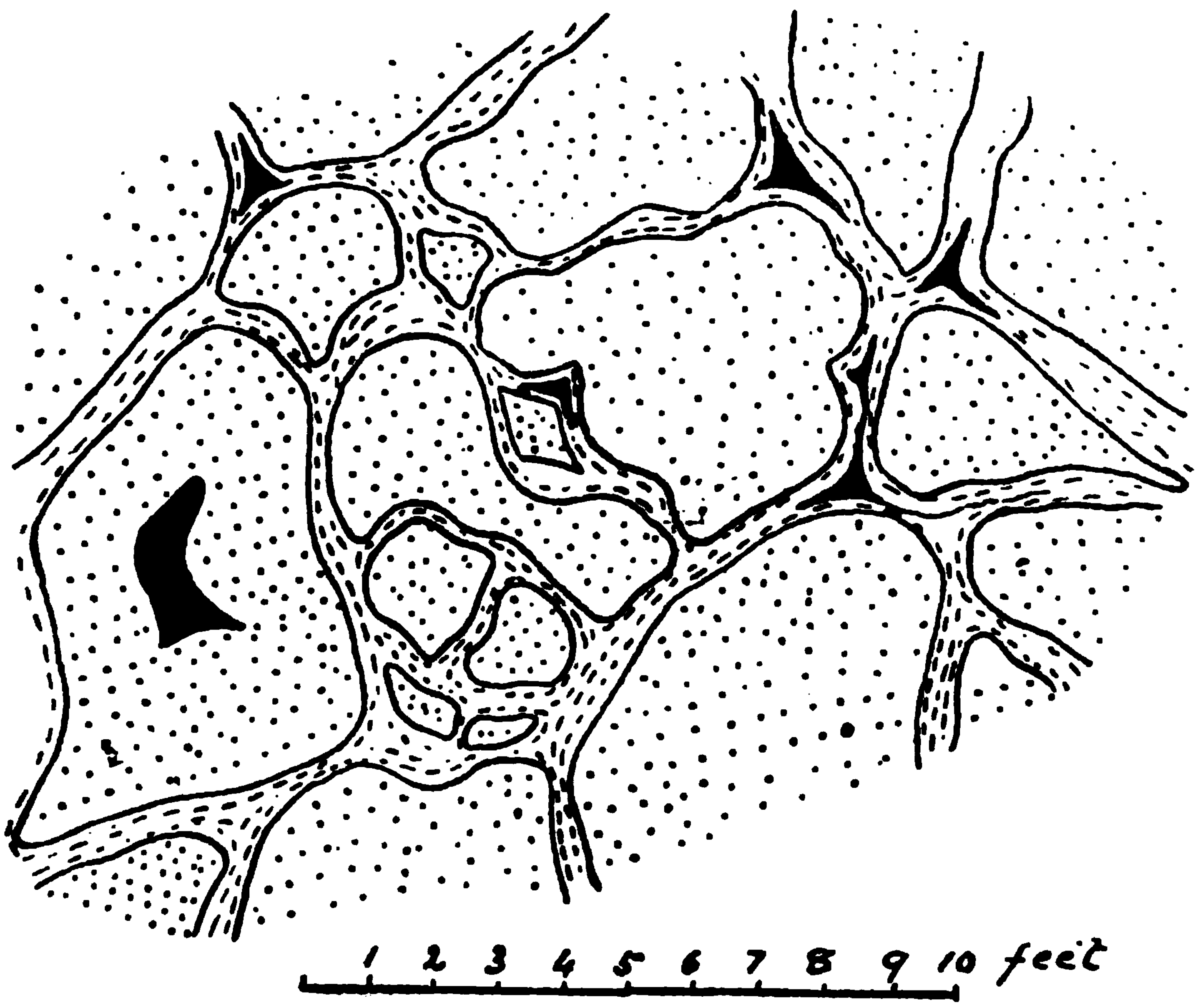



FIG. 6.—Plan of a surface of lava between Gasese and Upper Dikgathlon. The dotted areas within continuous lines represent unmodified lava; the areas marked with broken lines represent the dark rock made of chalcedony, chlorite, etc.; and the black areas are white quartz.

felspar, and probably also augite. The felspars are largely replaced by colourless aggregates, which are partly made of chalcedony. There is much opaque dusty matter, but no definite iron ore. In this matrix there are many small porphyritic pseudomorphs of a colourless fibrous mineral, probably after a rhombic pyroxene.

Some layers of lava present a peculiar structure. They are made of more or less rounded but irregularly-shaped blocks of lava, green in colour, separated by a darker and rather serpentinous-looking material, with a laminate structure parallel with the nearest surface of a lava block. (See figs. 6 and 7.) In

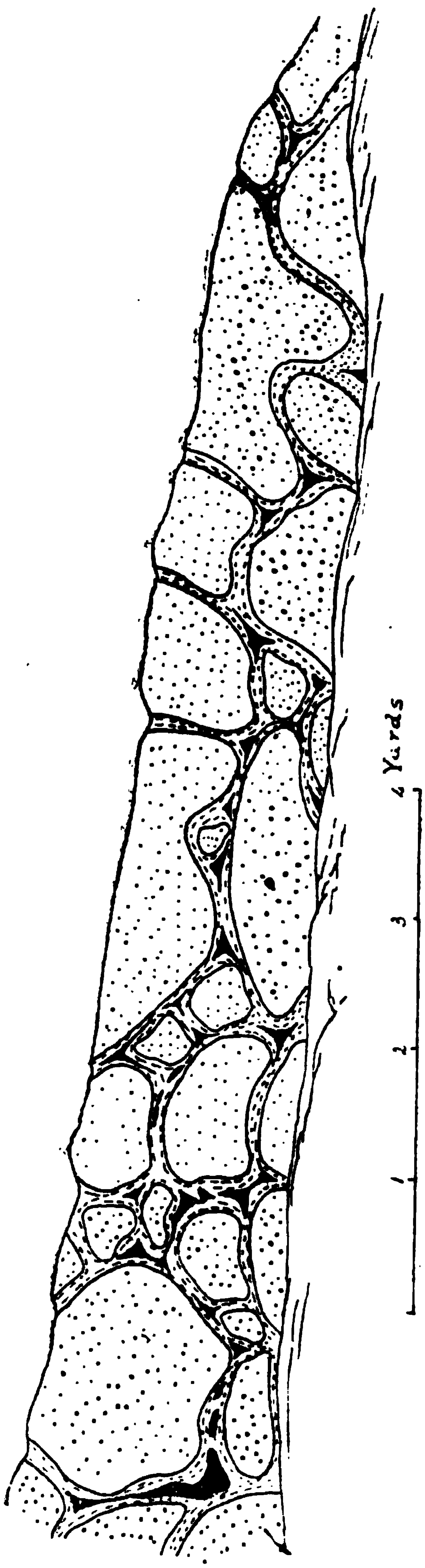



Fig. 7.—View of a vertical section through a lava flow exposed on the Mashowing below the large water-hole at Madebing. Dotted areas are lava blocks; the broken lines represent the darker rock, supposed to be mainly the products of decomposition of the lava; the black areas, quartz.

the larger interstices between the blocks there is frequently a mass of white vein-quartz, which may send thin veins along the nearest bands of dark rock, and may thus be connected with neighbouring quartz masses in other interstices; occasionally a mass of quartz is seen within a solid lava block. A plan of a horizontal section through this type of lava is seen in fig. 6, and the appearance of a vertical section through such a layer is shown in fig. 7, drawn from a lava bed in the Mashowing at Madebing. A thin section (1737) from one of the lava blocks shown in fig. 6 is seen under the microscope to be made of a matrix of felted bunches of radiating microlites and ill-defined grains, together with some recognisable felspar crystals, partly altered to a colourless aggregate; enclosed in this matrix are pseudomorphs of small quartz mosaic and chlorite, perhaps after a pyroxene. This is the only section cut from the blocks, and it indicates considerable alteration of the lava. The rock is not vesicular. A section (1738) from the darker laminated material between the blocks shows no sign of the structure seen in the lava; it consists of chlorite, chalcedony, epidote, an almost

isotropic, very pale green substance in aggregate form, filling veins and interstices, and spherical and laminated aggregates of an almost opaque pale brown substance. This dark rock may perhaps be fragmental lava, *i.e.*, tuff, altered in place; it at least appears to be due to the collection of decomposition products between blocks of less altered lava, ordinary white vein quartz filling up the spaces left after the deposition of all the dark alteration products.

The lava bands affected by this peculiar structure vary from 3 to about 10 feet (on the Mashowing) in thickness. In small outcrops the rock looks like an agglomerate, but in the large exposures it is obvious that the formation of the apparently agglomeratic structure took place during the outpouring of the lava, and that it is due to the separation of the lava into large and small blocks, fitting more or less closely, but kept apart by the deposition of the dark material or its forerunner. The dark material is very like the matrix of a true breccia found near Dikgathlon, and described below.

These peculiar lavas of the Kuruman and Mashowing Rivers undoubtedly present structures having some resemblance to those in the "pillow" lavas or "spheroidal" basalts of other countries,[1] but a noteworthy difference from the foreign rocks of which descriptions are available is that the latter are in each case amygdaloidal, while the Bechuanaland pillow-lava does not contain amygdales in the outcrops examined. The only cases in which there were original cavities in the lava blocks are the few masses with large patches of vein quartz within them, one of which lies within the area shown in fig. 6. Another point of difference from several of the foreign occurrences is that in our rocks the little altered lava blocks are separated on all sides, so far as they are visible, from the neighbouring blocks. The photograph on Plate II. of the *Silurian Rocks of Scotland*, Vol. I., represents a rock very like some of the Kuruman River outcrops, but the interstices in the Downan rock (illustrated in the plate mentioned) are filled with limestone. It has been remarked that cherts, some of which have been proved to contain Radiolaria, often accompany lavas with the pillow-structure; in Bechuanaland red banded jaspers do occur in the neighbourhood of the peculiar lavas, but they were not found *in situ*. In Griqualand West outcrops of the red jaspers were found amongst lavas of the Ongeluk series, but the pillow-structure was not noticed

[1] Ransome, *Eruptive Rocks of Point Bonita*, Bull. Dept. Geol. Univ. of California, 1893, vol. I., pp. 75-85. Amygdaloidal basalt. Cole and Gregory, *On the Variolitic Rocks of Mount Genèvre*, Q. J. G. S., vol. XLVI., 1890, p. 295. The structure is in a variolitic vesicular diabase. *The Silurian Rocks of Britain*, vol. I., 1899, Mem. Geol. Surv. of the United Kingdom, amygdaloidal lavas of Arenig age. *Ancient Volcanoes of Great Britain*, by Sir A. Geikie, contains descriptions of vesicular pillow-lavas from Scotland and Wales; vol. I., pp. 25, 193. Mem. Geol. Surv. of England and Wales, explanation of Sheet, 348, 1907. Amygdaloidal pillow-lavas of Devonian age.

near them. It is quite possible that the structure is developed in Griqualand West, and that it escaped detection.

The bright red jasper found in the Ongeluk group elsewhere[1] occurs below Gasese, though only fragments were seen. A thin section (1848) from a red and white banded jasper found below Gasese shows that it is made chiefly of chert with very minute clusters of red specks; sometimes the latter are collected together in spherical lumps. In parts of the rock there are irregularly-shaped grains of calcite or dolomite, and in the same parts there are very small short yellowish needles, slightly pleochroic and with straight extinction.

The Gasese outcrops are separated from those near Dikgathlon by a stretch of sand and limestone; the first met with belong to the Lower Griqua Town group, which here appears in an anticline with dips up to 15°. Immediately upon the glacial beds there rests a lava flow. A thin section from this rock (1740), which is dark green in colour and very hard, shows that it has been considerably altered, mainly by the coming in of much chalcedonic silica. There are numerous small porphyritic pseudomorphs of chalcedony and chlorite after some mineral, but the outlines are not well enough defined to allow the original mineral to be named; the ground mass is greenish owing to the amount of chlorite in it, and it contains many small but sharply-defined pseudomorphs after felspar; the chief replacing constituent both in the felspar form and in the rest of the matrix is chalcedony.

About two miles above Dikgathlon there is an agglomerate seen lying on a lava flow; the agglomerate consists of small and large blocks, angular and sub-angular in shape, embedded in a dark matrix. The fragments are of the spotted type, in which the spots are probably pseudomorphs after enstatite as in slice (1736) described above, but no section from the blocks has been cut. The matrix or alteration minerals alone are seen in slice (1741); it consists of chalcedony, epidote, and chlorite; but some small angular pieces of epidote-quartz-rock may represent lava fragments.

The outcrops cease about 1½ miles above Dikgathlon, and no rock other than surface deposits and gravel was heard of or met with either at the surface or in wells along the Kuruman River between Upper Dikgathlon and Matlapanin, a distance of over 100 miles along the course taken by the river bed.

Near Madebing the Ongeluk beds are frequently exposed in the Mashowing and Kgogole laagtes. Approaching Madebing from the west, the outcrops are first seen about a mile from the junction of the Kgogole and Mashowing; on the former river they occur at intervals for some nine miles up the valley, where they are underlain by the Lower Griqua Town beds; on the

---

[1] Ann. Rep. Geol. Comm. for 1905, p. 182.
Ann. Rep. Geol. Com. for 1906, p. 44.

Mashowing outcrops cease about five miles above the junction of the Kgogole, and there seem to be no further exposures until the Campbell Rand beds above Piet Quane, some 20 miles distant, are reached. I did not, however, see the whole length of this interval, only the eight miles above the junction and five below Piet Quane.

The lavas in this neighbourhood are fine-grained green and blue rocks, in part amygdaloidal, and some of them have the small dark pseudomorphs after enstatite so often noticed further south. The peculiar structure due to the separation of the lava into blocks and the formation of a darker substance and quartz veins in the interstices, as described on a previous page, is well seen in the Mashowing section.

The Upper Griqua Town beds were not determined in the area examined. If present, they are hidden under the sand east of the Korannaberg. As previously stated, the beds of the Black Rock may belong to this group.

## The Matsap Series.

This group of rocks which forms the Langeberg range in Griqualand West also builds up the Korannabergen, several isolated short ranges and kopjes in the south-eastern part of the Kalahari, and probably also the longer ranges in the same region called the Kareeboom hills, and the Onder Plaats and Groot Drink hills. Some of these hills were not visited. Several of them are isolated, and are made of rocks differing to some extent from the usual rocks of the Langeberg and Korannaberg, so that their position in the series of formations is rather doubtful.

### *(1) The Western Foothills of the Langebergen.*

The chief of the western foothills is the Sagoup range, which rises to a height of 4,981 feet[1] and has a total length of about 25 miles. The rocks are gritty coarse quartzites and finer-grained bluish quartzites. The dips are westwards, or W. 15° S., generally, but on the south-west corner of Rooiwal there is a gentle syncline; the angle of dip rarely rises above 20°. A few miles north of the Sagoup range there are low hills on the same line of strike between Malby and the Inchwanin water hole; one of these hills is an anticline.

Slates or sericitic quartz-schists were not seen in those parts of the Sagoup range visited, but sericitic slates occur in a dry well on the northern part of Omvrede, in the valley between the

[1] The heights given in definite figures in the text and on the maps are taken from the Annual Reports of the Surveyor-General for 1901 and later years.

The flaggy beds in this section are strongly ripple-marked.

On Garaphoane the series is exposed on each side of the Mashowing for a short distance. It there consists of quartzites and conglomerates. The pebbles are chiefly of quartz, but banded black and white cherts, green chloritic rocks, quartzites, dark slates, and some schistose magnetic rocks occur. The quartzites are false-bedded, and ripple-marked surfaces are often seen. They dip westward at low angles.

On Morokwen the series is poorly exposed, but the outcrops and a slight rise marking their position are sufficient to show that the Black Reef beds trend north-eastwards through the Reserve.

### *The Campbell Rand Series.*

The Kaap Plateau, which is made almost entirely of these rocks, was crossed between Vryburg and Takoon; nothing of particular importance was met with, no fossils were found in the rocks. On Armoed's Vlakte near Vryburg a rather peculiar looking rock was seen above the highest beds that could be placed in the Black Reef series. It is a gritty rock, which weathers with a brown scoriaceous-looking surface; in thin section (1713) it is seen to be a gritty rock, with much calcite or dolomite. The gritty constituents are chiefly quartz, but there are also fragments of felspar and a few small pieces of a felspathic igneous rock that may have come from the Pniel lavas or intrusive sheets associated with them. Deposition of quartz has taken place round many of the quartz grains, and there is also some chalcedonic silica. The carbonates form grains and rhombohedral crystals in the rock matrix, and also oolitic grains, of which the original concentric structure is usually only visible by ordinary light, owing to its partial obliteration by subsequent crystallization of the carbonates.

The plateau formed by this series is about 62 miles wide near Kuruman, but decreases to 24 miles west of Garaphoane, where it is crossed by the Mashowing. Northwards it maintains about the same width as far as Morokwen. Penning evidently noticed this fact, and attributed it to the thinning out northwards of the dolomites.[1] No definite evidence for this statement has been brought forward, and the rocks are so much concealed throughout the area that in the absence of deep bore-holes the facts are difficult, if not impossible, to obtain. The dips are everywhere low, and there may well be undetected faults and gentle folds which greatly increase the width of country occupied by this group in the plateau.

The dolomites and cherts are only seen along the Mashowing for a distance of about half a mile some four miles up the river from Piet Quane (Derwent on the Divisional maps). The rocks

[1] Penning, quoted in Wilkinson's paper cited above.

are blue crystalline dolomites, with a few chert bands in them, very like many outcrops between the Mashowing and the Orange River. North of the Mashowing no outcrops were seen near the road between Heuning Vley and Morokwen; sand and surface limestone cover the rocks completely. South of the Mashowing no outcrops were seen within five miles of the hills formed by the Griqua Town series for some 15 miles south of Piet Quane, but the dolomites and cherts appear frequently on Kooroon and Gamolilo, and further away from the hills on Foster and Padstow.

West of the Kuruman hills in this region outcrops are exceedingly scarce, and there was no evidence found to indicate the extension of the Maremane anticline as far northwards as the Kuruman River.

In the middle of the scattered ranges known collectively as the Korannaberg there is a ridge, about four miles east-north-east of the watering-place called Blaauw Krantz, made of a mass of Griqua Town beds occupying the axis of an overturned anticline in the Matsap series. On the east side of the ridge, in a small kloof, there is a much broken but thick band of dolomite, which seems to dip at high angles westwards under the Griqua Town beds. It is a blue and grey rock generally, but there are reddish streaks in it, and also some dark cherts. This is the most westerly outcrop of the Campbell Rand series yet seen in Bechuanaland.

## The Griqua Town Series.

In this district the Griqua Town beds were only seen in the Kuruman-Heuning Vley hills and the country to the west of them.

### *(a) The Lower Griqua Town Beds.*

These rocks form the Kuruman-Heuning Vley hills, an escarpment rising from the Kaap Plateau and limiting it on the west. For some 12 miles south of the gap cut by the Kuruman River the hills trend north-west, but between the Kuruman and Mashowing Rivers the trend is about N. 10° W. North of the Mashowing the rocks are very little exposed for some distance, but the position of the low hills made by the Lower Griqua Town beds on Dutton indicate a nearly northerly strike. North of the gap by which the conjoined Kgogole and Mokgalo laagtes pass through the belt of Lower Griqua Town beds, the general trend of the latter and of the hills formed by them is about north-north-east past Heuning Vley. I was on the hills some four miles north of Heuning Vley, and they are continued in a group of low hills for several miles further towards the north-north-east, then they apparently break off and reappear again at Skelek.

The dips are everywhere low, and are directed chiefly towards

For some 13 miles along the main range from Lukin to Top Dog the beds are very much folded, and the folds are well exposed on the sides of the steep kloofs which cut into the western flank of the range. These folds are overturned, and their axes dip eastwards at about 45°; they are not quite isoclinal, the eastern limbs of the arches are less steeply inclined than the western. Their general effect is to bring the beds down towards the west (see fig. 8). The rocks on this side of the range are the usual mottled coarse purplish quartzitic sandstones with isolated pebbles, probably belonging to the upper of the three sub-divisions into which the Matsap beds in the eastern part of the Langeberg were divided. No outcrops of the volcanic beds (middle division) were met with, but some large fragments were seen on Lapane; they may have been pieces carried down from the Olifants Hoek hills.

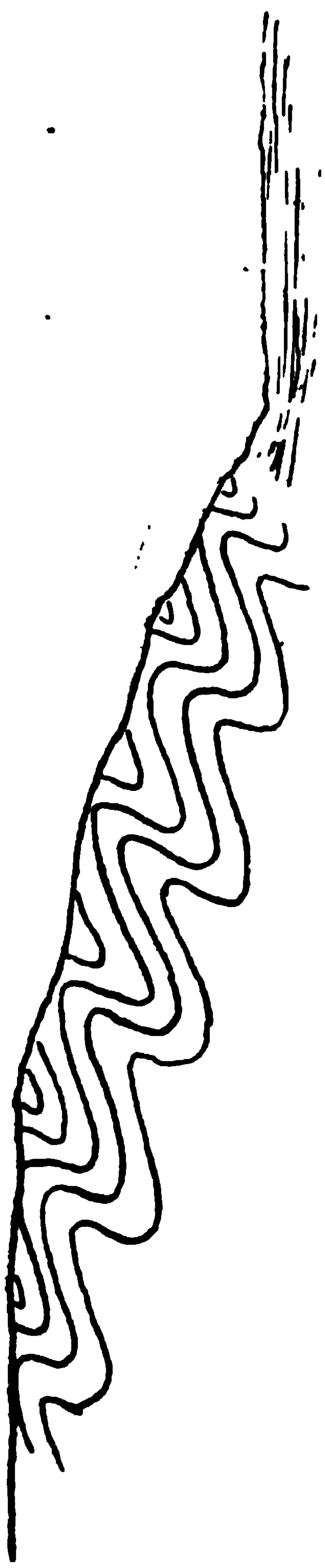


Fig. 8.—Diagrammatic sketch of the overturned folds seen in a long kloof west-north-west of Lapane beacon on the Langeberg. The length of the mountain slope is about 1½ miles.

### (4) *The Isolated Hills in the East of the Southern Kalahari.*

From the Inchwanin hill on the north to the Koodoos Kop on the south there are 10 isolated hills and ridges projecting from the sand. Their approximate positions are marked on the map. Of these only Inchwanin, Makokokoie, the hill five miles east of the latter, and the Kuip range were visited, but the characteristic appearance of the others left no doubt as to their nature.

The Inchwanin hill is made of the usual purplish gritty quartzites of the Matsap series, dipping about 3° south of west at angles between 20° and 30°. It is an important place, because there are numerous small holes in it which hold water for a long time after rain. The water in the largest hole was three feet deep and about eight feet across at the time of my visit. Some of the holes are small depressions at the intersection of cross-joints with the main joint-planes (E. 10° N.); the largest hole looks as though it had been enlarged by breaking off slabs of the quartzite. They are all several feet above the level of the sand, and are approached over a slope of rock which is rather dangerous for cattle to walk on. Another interesting feature here is the presence of numerous rock carvings of various kinds; representations of the giraffe, several kinds of antelope, lion, baboon, tortoise, men with bows and arrows, and various circles in concentric patterns, spirals, twisted lines, and small conical hollows two inches wide and one

deep. They are incised on smooth surfaces, which are covered with a thin brown hard film. Many of the lines are so shallow that they are scarcely perceptible on passing the finger over them. Others are much more deeply hollowed, evidently by repeated blows from a blunt instrument. The brown film has not been formed over the incised lines.[1]

For some 6 or 10 feet above the level of the sand the rocks at the south-western corner of the Inchwanin hills are very smooth, and in parts quite polished. They have a gently curved or flat surface, very like the front slope of *roches moutonnées*. Surfaces of this sort are frequently seen on low outcrops in the Kalahari, but they extend further up the side of the hill at Inchwanin than elsewhere. At first I thought the surface might be glaciated rocks recently stripped of Dwyka tillite, but they are not striated, and no tillite or boulders such as commonly occur in that rock were found in the neighbourhood. At other places along the hills the smooth polished surface is much smaller or altogether absent. There can be no doubt that the polishing has been accomplished by sand blown across the rocks within a few feet of the ground. The fact that such polished surfaces are restricted to within a very few feet of the surface of the sand and are never seen higher up confirms the general impression as to the movement of sand in the Southern Kalahari conveyed by the nature of the dunes, that at present the movement is slight, and has been so for many years past.

The Kuip range is made of the usual gritty quartzites, which dip towards W. 10° S., but at the south end the dip turns towards S.S.W., and there is a slightly projecting shoulder at the south-eastern extremity.

### (5) *The Inkruip and Scheurberg Ranges.*

The Inkruip range is made of gritty purplish quartzites, with sericite commonly developed; the beds generally dip S. 20° W., but on the eastern side there is an anticline. A rough cleavage has been produced which tends to obscure the bedding planes, and which is more important in determining the action of the weather than the bed planes. The range is separated by two miles of sand from the smaller Kakoup ridge to the north-west, but the Kakoup rocks almost certainly belong to the same formation as the Inkruip beds. The quartzites there probably belong to the Matsap series, though I did not find the red jasper pebbles in them.

The western range on Scheurberg was not visited. It is on the strike of the Inkruip beds, and presents a very similar appearance. They are both different in appearance from the

[1] Some tracings and photographs of these drawings were made and are in the South African Museum.

sharply serrated ridge, Scheurberg proper, on which the Trig. beacon stands, and which is made entirely of Kheis beds.

Circumstances prevented me from going to the southern end of the western Scheurberg ridge, where there must be an interesting junction with the Kheis beds of the hills trending N. 40° E. from Rooi Zand. The junction probably lies in the neighbourhood of the poort through which one of the roads from the Langebergen to Upington passes.

On looking at the map it will be seen that the places where the Kheis beds occur in the south-east of the sand-veld lie directly between the Langeberg-Korannaberg ranges and the western Scheurberg and Inkruip ridges or a line drawn through them and produced north-north-westwards. It is likely that the Kheis beds mark the position of a large anticline in the Matsap series.

*(6) The Outcrops at Kuis on the Molopo.*

About 86 miles north of the Kakoup outcrops of the Matsap beds the Molopo has cut through a belt of purple quartzites with red jasper fragments, which can without hesitation be referred to the Matsap series. The section was examined between Kolingkwane and Kuis, a distance of 12 miles, but I was informed that similar rocks crop out again 16 miles below Kuis on the Molopo.

In this part of the Molopo the valley is a steep-sided trough, about 150 feet deep and from 200 to 500 yards wide. There is no definite river bed; at places, especially at Kolingkwane, Mogogobe, and a short distance above Kuis, the Matsap beds crop out in many spots on the floor of the valley, sometimes forming a bar which extends almost across the valley. Generally the quartzites appear in steep cliffs, which at Kuis are vertical, for nearly or quite 100 feet above the floor of the valley. For considerable distances there are no quartzite outcrops, but here the sides are made of Dwyka tillite filling ancient valleys in the quartzites.

The rocks are grey, blue, and purple quartzites, often false bedded, dipping at high angles towards W. 20° S., or slightly nearer west.

There are no outcrops in the sandy country between those rocks and the Kuruman River, and from information got from various people during the journey, it seems very unlikely that there are any outcrops between this part of the Kuruman River and the Kuie and Kakoup rocks.

*(7) The Onder Plaats-Groot Drink Ridges and the Hills North-East of them.*

Though many of the quartzitic rocks described in this section of the Report are isolated, and therefore cannot be traced in continuity with the strata in Korannaberg or Langeberg, their litho-

logical characters enable one to place them in the Matsap series without much hesitation. Those now to be mentioned present some differences from the typical Matsap beds, and their position in the geological succession is at present more doubtful, though it will be seen that the reasons for placing them in the Matsap series are more weighty than those which would assign to them a lower or higher position. It is more convenient to call them Matsap beds than to make a new group of them.

On Groot Drink there are three ridges of quartzites and quartz phyllites, with thin conglomerates near the base, striking about N. 15°-20° W. (See fig. 3.) At the southern end the westernmost ridge is terminated abruptly on Sterkstroom by the Groot Drink-Sterkstroom fault, which has a N. 25° E. course. The two eastern ridges rise from the sand. The beds in the two western ridges dip eastwards, those in the easternmost ridge dip westwards, so there is a syncline here. The junction with the Wilgenhout Drift beds is seen on Sterkstroom, but further north it is concealed by superficial deposits. The lowest beds are sericitic quartzites, but a few feet up there are conglomerates with a quartzite matrix and pebbles of quartzite, quartz-schist, and quartz. The quartz-schist pebbles evidently come from the Kheis beds, but I found no pebbles of the green cleaved lavas or slates of the Wilgenhout Drift beds. Then follows a thick group of massive quartzites and quartzitic grits, more like the Matsap beds than any other rocks in this part of the Colony; they are distinctly bedded, and some of them are false-bedded. This westernmost range is continued north-north-west for about eight miles across Groot Drink, Onder Plaats, Zonder Huis to Zwart Kop, where it ends in sand. On Onder Plaats it consists of thin quartzites, with bands of thinly laminated micaceous phyllites, which are more micaceous than any of the phyllites seen in the eastern foothills of the Langebergen or elsewhere in the Matsap series, but the bedding planes throughout these hills are much more distinct and have greater result in determining the lines of greater weathering effect than the bed planes in the Kheis series. The two eastern ranges have similar characters.

The Karreeboom Vlakte range projects from the sand five or six miles north-east from the easternmost range of the three just mentioned. I did not visit it, but Mr. Lanham brought me specimens from it where the desert road passes through it north of the Karreeboom Trigonometrical beacon; these rocks are quartzitic grits of the Matsap type, like the coarser quartzites of Groot Drink and Onder Plaats. The trend of the Karreeboom Vlakte hills is about N. 20° W., as observed from a few miles south of them on Zwem Kuil, but north of the Karreeboom Trig. beacon it turns more to the north, and the Kamkuip beacon is placed on the continuation of the range.

The total thickness of the beds seen in the easterly dipping series on Groot Drink must be over 2,000 feet. They are certainly younger than the Kheis beds, fragments of which they

contain, and their position with regard to the Wilgenhout Drift beds shows that they are younger than the latter. There is no reason to place them in the Transvaal system, to no member of which have they any marked lithological resemblance. They resemble the Matsap beds in that they are chiefly coarse quartzites, but they do not appear to have fragments of red or brown jasper in them, and the less siliceous portions contain more sericite than is seen in the shaly beds in the Matsap groups of the Langebergen, etc. Their sericitic character can of course be explained by the fact that they have suffered considerable pressure and folding, as evidenced by their high dips, though the observed sections through the hills are not extensive enough to show repeated close folds, if present, like those exposed on the western flank of Langeberg.

The chief difficulty in accepting these rocks as of Matsap age is that the Koras series not far to the west are not cleaved or closely folded, and the Koras series is supposed to represent the Pniel group in this area. It is true, of course, that the latter correlation may be wrong. It is also possible that the down faulted block of the Koras group, assuming its greater age, was never subjected to the pressure that deformed the Onder Plaats rocks.

## The Karroo System.

Rocks belonging to this system were seen between the north corner of Upington Common and the neighbourhood of the German border north-west of Rietfontein, a distance of about 126 miles in a straight line running north-west, and between the German border on Obobogorop and Kolingkwane, 130 miles or so in a north-easterly direction. As pointed out in the Introduction, there is reason to think that a very large part of this great area is underlain by a thin layer of rocks belonging to the Karroo formation, though the rocks are very rarely seen.

By far the greater number of the exposures belong to the Dwyka series, but sandstones and shales that can be placed in the Ecca also occur.

The distribution and thinness of the Karroo deposits suggest that the present form of the ground in Gordonia is now not very different from what it was at the time of the deposition of the Dwyka series.

### *The Dwyka Series and Overlying Shales.*

The Dwyka series in Gordonia consists of boulder beds, in some places laminated and in others without lamination. These rocks, which may conveniently be called "tillites,"[1] are not often

[1] The term "tillite" was invented by Prof. Albrecht Penck whilst on a tour through South Africa in 1905; it is used for rocks which look like the well-known till or boulder-clay and allied rocks of Europe and America, but have a hard stony matrix. Its use does away with the necessity of such expressions as "hardened boulder-clay."

exposed, but their presence under the soil is indicated by the numerous boulders and pebbles of rocks foreign to the immediate neighbourhood left behind after their matrix has disappeared.

The first indication of the Dywka was seen in the north-western corner of Upington Common, where the Upington granite passes under a sandy soil, in which lie boulders of granite, quartzites, grits, blue diabases—some of them amygdaloidal—dolomite and chert. Some striated boulders were found here. On Areachap there is a well on the edge of a pan close to the roadside. The bottom of the well is in gneissose granite, which is overlain by some 50 feet of tillite, reddish in colour, containing boulders and pebbles of granite, gneiss, amygdaloidal diabase, banded black and red magnetic jasper like that in the Griqua Town beds, red jasper, quartzites, and a very hard quartzitic conglomerate. The uppermost 8 feet of the well section are shale with boulders, and there are two six-inch layers of clayey limestone.

Similar tillite with reddish matrix is seen in a well on Grond Neus. From this well were obtained some boulders of a peculiar igneous rock, not previously noticed either in the Dwyka or *in situ*; the rock consists of a dull white matrix with small dark crystals in it. Under the microscope (1815) the matrix is seen to consist of a confused mass of aggregated minerals, saussurite, like the decomposition product of some felspars, a little quartz, brown mica, and magnetite. The crystals are pseudomorphs of a green fibrous serpentinous mineral, with calcite filling wide cracks parallel to the green fibres, and some magnetite; their shape is like that of a pyroxene.

These wells were the only places where the matrix of the tillite was seen in this part of Gordonia, and further north the matrix is always grey or blue, as it is in almost all the other recorded outcrops of Dywka tillite in Cape Colony. The specimens brought to Cape Town by Dr. Nobbs from Norokei and Eenzamheid, 28 and 40 miles north-west of the Upington northern corner beacon, are greyish blue rocks.

In the immediate neighbourhood of Bloemfontein House the shales and thin sandstones of the Zwart Modder beds crop out, but towards the west and north the Dwyka covers these beds. Three miles west of the house there is a patch of thin shales with lenticles of clayey limestone, evidently belonging to the Karroo formation, and possibly resting directly upon the Zwart Modder beds without the intervention of tillite. The latter occurs round the shale area, and is of the usual grey colour, with boulders and pebbles of various rocks similar to those noted above from Areachap.

On Abiam there is a well sunk 30 feet through greenish grey tillite, containing many scratched boulders. There are many quartz-porphyry boulders here.

Between the north side of Bloemfontein and the neighbourhood of Rietfontein the surface is either loose red sand, or hard,

with immense numbers of pebbles and boulders scattered over it. These patches of hard ground are sparsely covered with small bush. The boulders and pebbles are of various rocks, and undoubtedly come from the Dwyka tillite. Striated boulders are quite as numerous here as on the tillite plains of Prieska or the Western Karroo in Calvinia and Ceres; there is indeed a close resemblance to these distant areas.

Near the south-eastern boundary of Wit Kop the main road passes near a low hill, with a beacon on it, conspicuous on account of the flatness of the surrounding ground, made of unusually hard blue tillite. There are many lenticles of compact blue limestone in the tillite of this neighbourhood, but the hard rock referred to above is not calcareous. A thin section of this rock (1820) shows characters that have been developed long subsequently to the deposition of the tillite, and are very probably due to the proximity of a dolerite intrusion not yet exposed at this spot. Near Wit Kop dam a well penetrates 25 feet of hard blue tillite, and then enters dolerite of the usual Karroo type. The beacon-hill rock consists of angular and rounded grains of quartz and felspar, chiefly the former, quartzite, and a felspathic igneous rock that may have come from the Pniel lavas, set in a fine-grained matrix of various minerals, amongst which quartz and biotite have alone been recognised. The mica is the red-brown strongly pleochroic sort found in the slaty rocks of the Malmesbury beds near their junction with granite; it is very abundant in minute flakes, and has undoubtedly been developed *in situ*. Another new mineral is also very abundant; it is colourless, with fairly high refraction and weak double refraction (about that of quartz); it forms very minute grains and elongated grains, with occasional straight edges, parallel to which the mineral extinguishes; it has not been identified. Some metallic grains are probably magnetite; they are frequent, but usually very small.

Between the well and the dam at Wit Kop there is much hard calcareous tillite of a pale grey colour, often stained yellow or brown by oxides of iron. A thin section of this rock (1824) shows chips and grains of quartz, felspar, quartz, grit, quartzite, chert, micropegmatite, and cherty limestone or dolomite, in a matrix containing much calcite.

Amongst the numerous boulders, some of them striated, lying on the surface on Wit Kop, and evidently weathered out from the tillite in place, the following were noted: Granites and gneiss, many with white felspars porphyritically developed, and generally with biotite, more rarely muscovite; fine-grained rocks of similar composition; the porphyritic type is not known amongst the Upington granites. There is also a red felspar rock, with a matrix of red micropegmatite visible under a lens. Amygdaloidal and compact blue-green diabase, such as might come from Pniel lavas and dykes of pre-Karroo age; one of these types of rock is remarkable, in that it contains green epidotic pseudo-

morphs after felspars up to $1\frac{1}{2}$ inches long. There are quartzites and sandstones of various kinds; some are bluish or white, others reddish, like many beds in the Zwart Modder series; grits; felspathic grits like the felspathic rocks at the base of the Black Reef beds in Bechuanaland. There are conglomerates with quartz and chert pebbles, like the Black Reef conglomerates, and another conglomerate with dark quartzitic matrix and large pebbles of chert and banded jaspers, some of which are red. (This conglomerate occurs in large boulders, often several of them lie near each other; they have caused some prospecting, their presence being supposed to indicate a conglomerate or "banket" reef underground; they have, however, certainly travelled far from their parent beds, the position of which is unknown, but probably lies north of Gordonia.) There is much dolomite and chert, and red and black banded magnetic jaspers, but no yellow and black jaspers like the brown rocks in the Griqua Town series of the Kuruman hills, etc. This collection of boulders is not very different from that which one finds in the Dwyka tillite along the south of the Karroo, but granites are less abundant in the north and the brown Griqua Town jaspers apparently absent, as well as typical Matsap purple quartzites. The red micropegmatitic rock and the dark conglomerate seem to be peculiar to the Gordonia tillite.

On Springbok Vley some of the flat ground is directly underlain by the tillite, and boulders of a coarse porphyritic granite two feet long have weathered out from it. There are also numerous calcareous layers and spherical concretions. The highest part of the tillite here is a rock poor in pebbles, and above it lies a sheet of intrusive dolerite, forming the slopes of the low hill on which Springbok Vley Trigonometrical beacon is placed. Above the dolerite are some thin patches of hardened sandstones and shales, only 3 or 4 feet thick, without pebbles.

On Obobogorop there are wells sunk 70 feet in grey shale and mudstone with few boulders, though the surrounding ground is covered with the usual assortment of boulders and pebbles. No black shales are exposed. The tillite is exposed again near the north-west corner of Lang Vley, where it is again capped by dolerite.

On the west side of the pan on Onderste Narougas there is a plain of hard ground with boulders; a water cutting reveals grey shales with few boulders, and thin lenticular limestone beds.

On Uitzak the usual boulders occur on flat ground near the northern boundary, but the boulder beds are overlain by 150 feet of thin dark grey shales, containing plant fragments, amongst which *Glossopteris* was found. These shales form a krantz capped by dolerite. These shales were followed at short intervals round the western side of Kopjes Kraal pan across Oxford to Schepkolk; on the two latter farms they contain striated boulders, but these decrease in number upwards as the rock is followed into the dolerite-capped hills called the Eierdop

range. A calcareous sandstone bed in the Dwyka series on Schepkolk (1832) is made of grains of quartz, felspars, some muscovite and bleached biotite, and zircon, set in a matrix of calcite, which is a mass of rather large interlocking crystalline areas.

Shales with boulders are exposed in a pit on Schepkolk, near the western side of Haakschein Vley.

On the Eierdop hills about 60 feet of shales without boulders are exposed. They contain silicified wood of the type found in the Ecca shales in several parts of the Colony. Above them is a prominent white band, due to the presence of five feet of whitish coarse arkose, a rock which has not been recorded from the Ecca or Dwyka series elsewhere. A thin section (1831) examined under the microscope shows that the rock is made of grains of quartz, orthoclase, and occasionally plagioclase, with a few pieces of garnet and brown mica. The felspar is cloudy and nearly opaque. Above this arkose there is only dolerite, to the presence of which the hills owe their existence.

On Mooi River and near Rietfontein there are layers of gravelly rock with calcareous matrix in the shales containing boulders. The gravel layers are only six inches thick at most, often thinner, and they are sometimes contorted. The pebbles in those layers are very abundant and closely packed, and they do not exceed three inches in length.

Around Rietfontein boulders weathered out from the Dwyka tillite are scattered abundantly over the ground; between the village and Sannah's Poort they are remarkably abundant, and their average size is larger than usual. Well-striated boulders can be found without difficulty. They consist of various rocks of the same kinds as those quoted above from Witkop. About a mile and a half from the German border at Sannah's Poort, down the stream-bed leading to Rietfontein, the base of the Dwyka is exposed in section. This is the only place where the junction was seen in a position where it could be closely examined; the other exposures of it were down wells. The base of the Dwyka is a grey unstratified tillite with many boulders. The rocks underlying it are thin shales dipping south-south-east and belonging to the Zwart Modder series. I could find no striated surface; the shales are broken at the junction, and are obviously unfavourable rocks for retaining glacial striae.

Some small patches of pebbly shale are exposed at the surface in the western part of the great Haakschein Vley, but in the eastern part of the pan itself only beds which resemble the Zwart Modder shales and sandstones were seen. About three miles north of the Wind Hoek dam there is a small kopje of, probably, Dwyka shale, a softer and greyer rock than the Zwart Modder shales of Blaauw Krantz, containing pebbles, amongst the sand dunes east of the Vley.

*Exposures in Wells along the Kuruman River.*

The well at Witdraai, about three miles up the river from its junction with the Molopo, is 80 feet deep. The upper 40 or 50 feet pass through sandy limestone of recent age, but below that level thin grey and greenish shales of fine texture, which break up rapidly under the influence of the weather, were met with. These may belong to the Karroo formation, though no delnite proof was obtained. The only other well which reaches the rock underlying the surface deposits is at Matlapanin, 70 miles by road up the river from Witdraai. I was at the well during the night, and could not find the thickness of the superficial deposits, but the well is 58 feet deep, and quantities of tillite with boulders of crystalline limestone, diabase, and gneiss, two of which were found to be typically glaciated boulders, have been thrown out from the well. Some of the material is boulder shale.

*The Kuis-Kolingkwane Section.*

Along the Molopo from Kuis to Kolingkwane the Dwyka tillite fills old valleys in the Matsap beds. Both formations are overlain by superficial limestones and other rocks, and are only exposed in the valley of the Molopo.

Between Kuis and Mogogobe the Dwyka forms two wide bands, separated by a narrow steep-sided ridge of Matsap quartzites. The beds were traced 80 feet up the side of the valley. The outcropping beds are brown-weathering hard grey-blue limestones and thin sandstones; they lie horizontally. Outcrops of tillite are rarely seen, and appear to be confined to the lower part of the slopes, but higher beds must contain boulders, for weathered out boulders are not only found on the lower slopes where the outcrops were seen, but also occur some 40 or 50 feet up. Several typical glaciated boulders were found at four or five places where a search was made, not only below Mogogobe, but between that place and Kolingkwane. The most abundant rock forming the boulders is cherty limestone or dolomite from the Campbell Rand series, but granites, gneisses, and amygdaloidal and compact diabases were frequent.

Between Mogogobe and. Kolingkwane the tillite and overlying sandy shales and limestones occur in a similar manner.

The time at my disposal for the examination of the 12 miles of the Molopo between Kuis and Kolingkwane was very limited, and I could not make a careful search for exposures of the junction of the Dwyka beds with the Matsap quartzites; it is probable that the junction is visible somewhere between the places mentioned, though there is much debris from the superficial deposits which cap the steep slopes.

It is of course impossible to trace the boundaries of the Dwyka beyond the narrow limits of the valley, but enough is visible to

prove that the tillite and associated Karroo beds fill valleys over 100 feet deep in the Matsap quartzites; the old valleys cross the Molopo at about a right angle and were deeper than the Molopo valley now is. As the right bank of the Molopo is in the Bechuanaland Protectorate, the Karroo formation extends into that territory for an unknown distance.

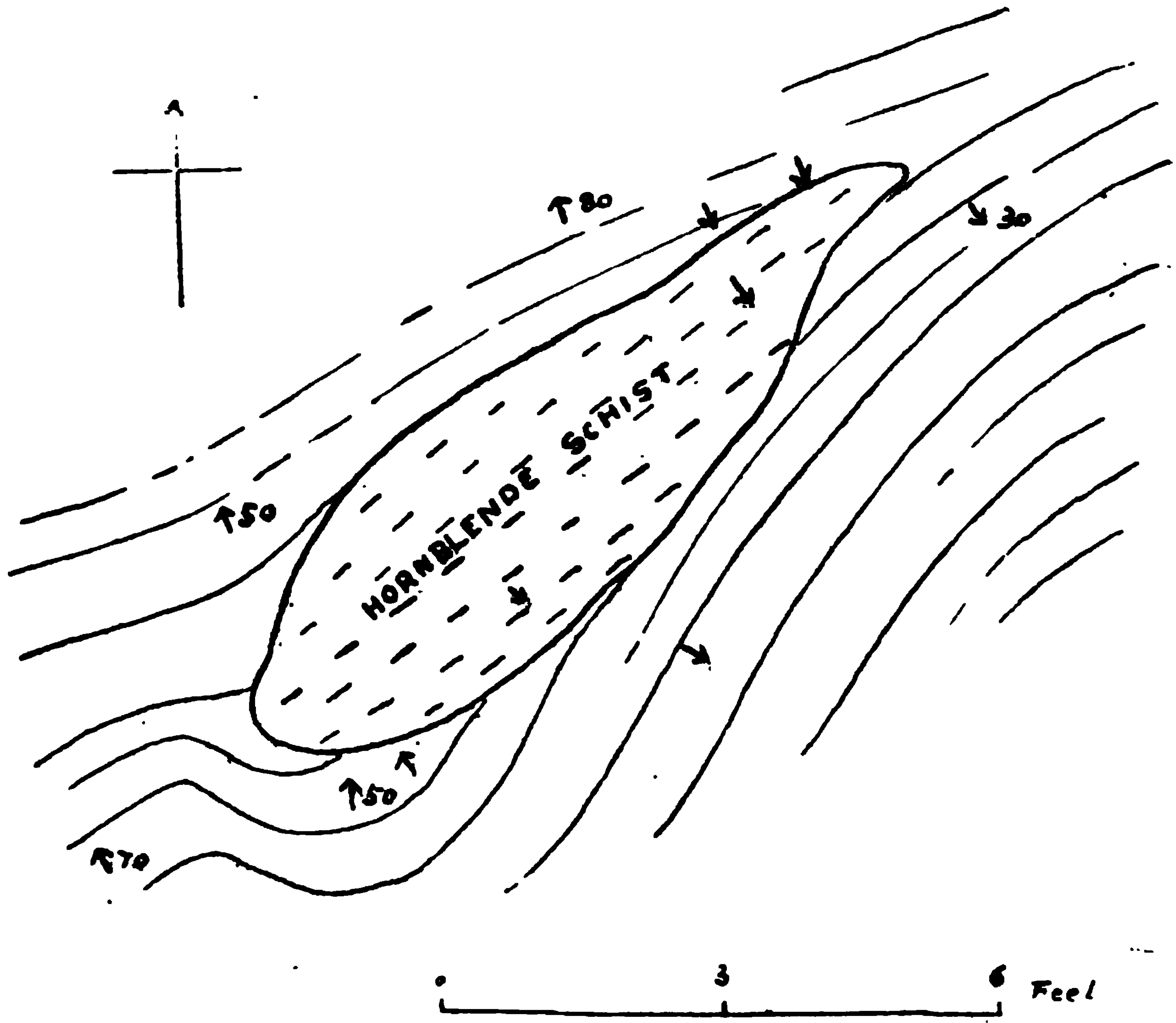



FIG. 9.—Plan of "eye" of hornblende-schist in quartz-schist on Kheis.

## INTRUSIVE ROCKS OTHER THAN GRANITES.

Dykes and sheets of various igneous rocks penetrate many of the sedimentary formations from the Kheis beds to the Karroo formation in this district. They are described below in the probable order of their intrusion.

### *(1) Schistose Dykes in the Kheis Series.*

On the farms Kheis and Tsebe there are many narrow dykes of a dark somewhat schistose rock. Usually the dyke either follows the schistose planes in the Kheis beds or forms a small angle with them; occasionally a dyke cuts across the schistose lanes at angles up to 45°. The ends of the hornblende schist

masses are rounded off, as in figs. 9 and 10. The dykes may be of any size from a few feet to more than a mile in length.

The rocks of all these dykes are very much alike and in the hand specimens remind one of hornblende-schist, but in some there is little evidence of parallel structure. Specimens from five dykes were cut for the microscope. Section (1756), from a dyke 4 miles north-east of Kheis, consists of hornblende, chlorite, zoisite, epidote, quartz, ilmenite and sphene, and calcite. No

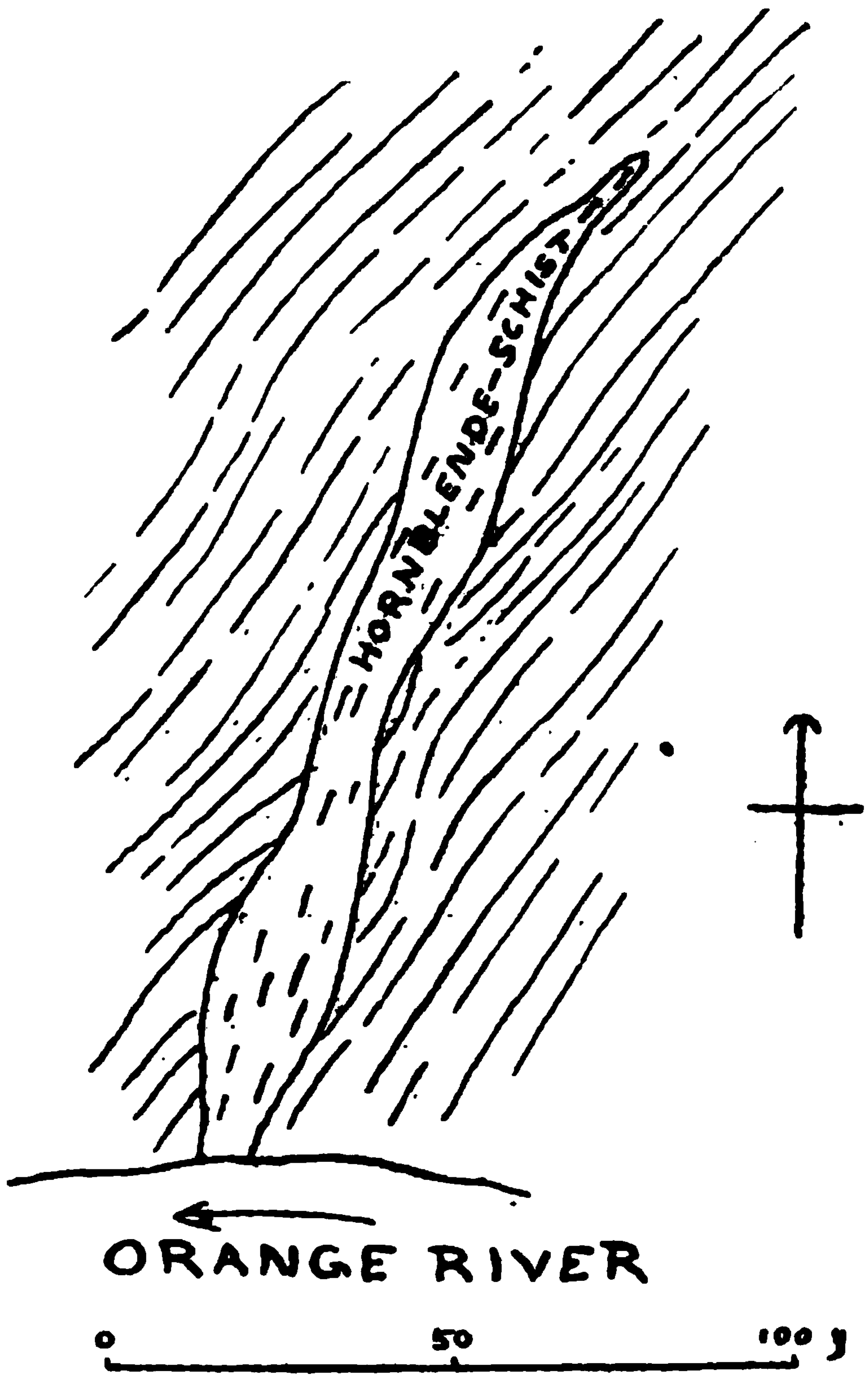



FIG. 10.—Plan of a hornblende-schist dyke in Kheis beds, Khejs.

parallel structure is discernible. The hornblende is in irregular plates and fibres; it is pleochroic (X colourless or nearly so, Y olive green, Z blue). The chlorite is in nearly rectangular lath-shaped sections. The other minerals are in small grains, and no felspar is visible. There is very little ilmenite left, but there are skeleton forms of it surrounded by aggregates of sphene and leucoxene. A rock from the 4th dyke below Kheis (1757) has more hornblende in it, otherwise it is similar to the last rock. A slice from a dyke one mile below Kheis (1758) is just like the first rock. One from 600 yards east of

Kheis Police Camp (1759) is a rather similar rock, in which the chlorite is more abundant and in larger crystals. Section (1760) from the "eye" of hornblende schist shown in fig. 9 consists of a granulitic mixture of the same variety of hornblende as in the previous rocks, quartz, epidote and perhaps zoisite, and magnetite or ilmenite and sphene, but apparently without chlorite. These hornblende-schists differ from the hornblende-schists of Garaphoane in the variety of amphibole as well as in other details, and they are not like the hornblendic rocks of Upington Common. They are probably greatly altered dolerite rocks which invaded the Kheis beds before the latter became schistose. That the hornblende schists have been greatly sheared is obvious from their appearance in the field; they have a parallel structure and the schistose planes often turn in direction in conformity with the nearest planes in the Kheis schists.

### *(2) Other Intrusions of Pre-Karroo Age.*

A dark band lying in the quartz-schists of Uitkomst was taken in the field to be a dyke of the Kheis type, but a thin section of the rock (1805) shows it to be of quite a different nature. It has a well-developed granulitic structure, the various minerals form more or less uniformly-sized grains; they are green pleochroic hornblende of the kind that occurs in the Upington augite-hornblende-granulite, quartz and plagioclase, together with some magnetite and a little brown biotite. This rock is more nearly related to the granite intrusions of Upington than to the more basic altered dykes of Kheis.

A narrow dark band in the Kheis schists of Achterkop is made of large and small ragged plates of pale pleochroic blue-green hornblende like that of the Kheis dykes. It (1845) also contains chlorite, an epidote-zoisite mineral, and very much of a colourless aggregate of quartz and possibly felspar.

There is a quartz-diabase dyke 150 feet wide traversing the Kheis beds of the Kuie pan nearly parallel to their strike; it is slightly finer grained at the margins. Thin sections (1749 and 1750) show that it is a holocrystalline rock, chiefly made of felspars, augite, hornblende, quartz, biotite and magnetite. The augite is colourless and has partly idiomorphic forms; it has the basal striation. The hornblende occurs as continuations of the augites, they have a cleavage in common; the hornblende is a moderately pleochroic green variety, and seems to be an original constituent; it is often partly changed to chlorite. Much of the felspar is considerably decomposed with the formation of sericite, especially in the middle of the crystals, which are partly idiomorphic and are plagioclase. There is also much orthoclase forming micropegmatite with quartz in the coarser rock. The

biotite is mostly altered to chlorite. There is much magnetite and a little apatite, and calcite in rather large masses. The finer-grained rock has no micropegmatite, and the augite is in small grains.

At Masilibitsani, on the Mashowing, there is a quartz-porphyry dyke which takes an S-shaped curve across the Mashowing; it commences on the south side of the river and soon attains a thickness of 10 feet, and has a N. 15° W. course; it swells to 80 feet and bends round to E. 20° N., crosses the river and turns N. 20° W., disappearing under superficial deposits. Along the two edges in contact with the granite, the rock is much finer grained than elsewhere. The middle part consists of corroded quartz crystals lying in a matrix of interlocking quartz areas clouded by minute specks and flakes of various kinds, and green chlorite. Calcite is an abundant constituent as very small grains (1723). Two slices (1624, 1725) cut from the finer-grained edges show a flow-structure parallel to the walls of the dyke. The matrix is separated under crossed Nicols into smaller areas than in the middle part of the dyke, but is otherwise similar; there are small specks of a sericitic mineral. There are clear oval areas of quartz-mosaic, which may represent quartz crystals, but there are no uniform corroded quartz crystals as in the middle rock. This dyke is only seen traversing granite, but it is possible that it was a feeder of the acid lavas of the Zoetlief beds, an outlier of which occurs about 13 miles further up the valley.

There is a small mass of apparently intrusive rock in the inlier of the Campbell Rand and Lower Griqua Town beds in the denuded anticline of Matsap beds east of Blaauw Krantz. It is a very much altered rock (1847), consisting of epidote, chlorite, quartz, possibly some felspar along with the quartz, and much magnetite and ilmenite with granules of sphene. Its original structure is obliterated.

In the Lower Griqua Town beds, near Lower Dikgathlon, there is a dyke of almost black rock about 100 feet wide with a northerly course. A thin section of this (1739) shows it to be an altered rock with scarcely any original structure preserved; it consists almost entirely of quartz and chlorite. There is some clear quartz, apparently original, and round these patches, which look as though they filled spaces between felspars or other constituents, new quartz has grown, crowded with small specks of a chloritic mineral, which also occurs alone in irregular patches.

Through the granite of the Detseping Reserve, opposite Keang on the Mashowing, there is a long diabase dyke about 200 feet wide. It consists (1721) of large chlorite pseudomorphs after an apparently rhombic mineral, probably enstatite,

embedded in a mass of alteration products, chlorite, epidote, and tremolite, together with fairly large and fresh augites, which are in process of conversion into pale uralitic hornblende; there are also patches of leucoxene.

The three intrusions of diabasic rock near the Orange River on Groot Drink, Leeuw Draai and Koras have some features in common, and may perhaps belong to one period of igneous activity. They do not closely resemble any other intrusive rocks in this area, and perhaps they are more like the fresher lavas of the Koras series than any other igneous rock in the north of the Colony. They all occur along lines of faulting, and have a strong general similarity in appearance.

The Groot Drink rock forms an oval outcrop exposed over a length of about three miles in a north-north-east direction; it lies between the greater part of the Wilgenhout Drift beds north of the river and the Sterkstroom fault, but the contacts are not exposed. A thin section (1774) shows it to be a fairly fresh glassy ophitic doleritic rock. The augite is quite fresh and is in irregularly-shaped, rather large colourless ophitic masses enclosing felspar and pseudomorphs of a greenish, slightly pleochroic mineral agreeing with bastite; remains of the cleavages in the bastite lie parallel with those of the augite; these pseudomorphs probably represent a rhombic pyroxene. The felspars are fresh and have symmetrical extinction about twin plains up to 27°, indicating the composition to be that of labradorite; they and the augite are very like the similar minerals in the usual type of the Karroo dolerites. There is much brownish interstitial matter, which was certainly glass once, but it is now no longer isotropic, though its constituents have not sufficient definiteness to be determined; it contains a few small felspars and augite grains. There is very little iron ore and no mica.

The Leeuw Draai intrusion has a wedge-shaped outline north of the river, and separates the Wilgenhout Drift beds from the Koras lavas for some four miles along a very probable fault; it is certainly intrusive and later than the lavas west of it. A thin section (1785) shows it to be a fine-grained rock with a large amount of semi-opaque devitrified glass, changed into an obscure mixture in which epidote grains are discernible, and also very small curved microlites. In this material as matrix there are very numerous, but small, grains of colourless augite, often showing prism and pinacoid faces, and small felspars which give symmetrical extinctions on the twin planes up to 25°, probably including members of the andesine-labradorite series. There are occasional small patches of chalcedonic silica playing the part of matrix. Some ilmenite and leucoxene are present. In the only slice cut there are no bastite pseudomorphs as in the Groot Drink and Koras intrusions.

The Koras rock is the smallest of the three masses so far as

it is visible on the north bank of the river; it occurs for a mile, or rather less, between the Koras sediments on the north-east and Kheis beds on the south-west, and it produced metamorphic changes in the former (see p. 56). In thin section (1794) it is seen to be very like the Groot Drink rock. There are numerous ill-formed pseudomorphs of bastite after a rhombic pyroxene in many cases partly or entirely surrounded by colourless augite. The augite is in grains and ophitic patches enclosing felspars. The felspars are more altered than in the Groot Drink rock and seem to belong to a less basic species than labradorite. There is much brown devitrified glass containing grains of epidote and chlorite, and also magnetite, with a tendency to form linear groups, but this feature is not nearly so well developed as in the Koras amygdaloids.

### *(3) Dolerites of the Karroo Type and Related Rocks.*

Rocks more or less closely related to the well-known Karroo dolerites were found traversing the granite in the neighbourhood of Genesa, Morokwen, and Takoon, in the Kheis beds at Tsebe, near Kheis, and in the Karroo formation and the Zwart Modder beds from Witkop northwards, but it is only in the latter area, the north-western corner of the district described in this Report, that they are of much importance.

On Request, a farm on the north-west side of the Genesa Reserve, there are two wells sunk on a dolerite dyke, which has a course about W. 15° S. In thin section (1717) the rock is seen to be a coarse dolerite without olivine. The augite is very pale brown in colour, has occasional basal striation and is often twinned on (100); it forms irregularly-shaped pieces between felspars and has a tendency to be ophitic, but that structure is not well developed. The felspar is labradorite, or near it. There are small quantities of green hornblende and red biotite; the hornblende is usually in parallel position with augite. There is a considerable amount of magnetite. Some small interstitial patches of quartz-felspar micropegmatite are present.

On the Morokwen Reserve a few fragments of dolerite were seen a mile west of the large pan, but no outcrop was found.

On the Motiton Reserve, four dykes of a rock looking like the Karroo dolerite were seen. The longest one traverses both the granite and Black Reef quartzites in a N. 20° E. direction near Motiton. A dyke parallel to this one crosses the river south of the store at Takoon. This rock has the usual mineral composition of an olivine-dolerite, but under the microscope it presents (1630) a remarkable appearance owing to the felspar crystals enclosed in ophitic masses of augite, being arranged in radiating bunches. The olivine is abundant and contains magnetite in grains and an opaque mineral in minute flat dendritic-looking patches arranged parallel to the vertical axis. On examination under a high power, these growths, which are

only seen clearly in sections cut nearly perpendicular to an optic axis of the olivine, are found to be made of straight narrow blades, meeting at a point or along a median line. There is a small amount of red biotite.

Two other dykes near Takoon have a north-easterly course. They appear to be dolerites of the Karroo type, but have not been determined under the microscope.

On the farm Tsebe, south-east of Kheis, there are two broad dykes of a black dolerite-like rock running S. 10° W. through the Kheis beds, which strike S. 30° W. The eastern dyke is 100 feet wide and the western 150 feet. They were taken for ordinary Karroo dolerites in the field, but a thin section from the western dyke (1762) shows that the rock, though presenting many points of resemblance to the olivine-dolerites of the Karroo, has a much more basic composition, and is related to the rocks called augite-picrite. It consists of olivine, augite, biotite, magnetite, and a little felspar. The olivine is in colourless grains or ill-developed crystals, much cracked, and it contains magnetite in large and small grains and crystals; it also contains very small opaque scales and dendrite-like growths arranged parallel to the vertical axis, just like those in the olivine of the Takoon dyke. The augite has a very pale brown colour, and is in untwinned irregular pieces of considerable size, but it does not form ophitic masses; it encloses a few grains of olivine. The biotite is the strongly pleochroic red variety seen in many of the Karroo dolerites; it forms irregularly-bounded plates, often enclosing magnetite. The felspar forms irregular patches and is peculiar; it does not form good crystals with well-defined properties as in the dolerites; the twinning is irregular, the different parts of individuals or neighbouring individuals not being sharply separated in polarized light, but both albite and pericline twinning seem to be developed. The rock differs from the dolerites in the small amount of felspar present and the much greater quantity of olivine and red biotite.

A third dyke, of the ordinary dolerite type, was seen south-west of the picrite dykes on Tsebe.

The dolerites of western Gordonia were first seen at Witkop, but the first outcrops at the surface occur at Springbok Vley, some seven miles north-west of Witkop dam. At Witkop, a well has been sunk through the Dwyka tillite into dolerite, which lies 25 feet below the surface. This rock (1825) is a fine-grained ophitic dolerite of the usual Karroo type; it contains a few olivine grains, converted into serpentine, and some biotite, which is largely changed to chlorite. The rest of the rock consists of augite, labradorite and magnetite. The presence of dolerite underground a few miles further south is indicated by the metamorphic changes suffered by the tillite, described on p. 78.

On Springbok Vley, a sheet of dolerite, 80 feet thick, lies between Dwyka boulder shale below and hardened sandstones

forming the top of the hill on which the Trigonometrical beacon stands. The rock is deeply weathered into large spheroidal masses. It has caused the development of biotite in the overlying felspathic sandstone (1822).

The western corner beacon of Lang Vley is on a dolerite kopje, which seems to be an outlier of a sheet, possibly the same sheet as that on Springbok Vley, for it lies on Dwyka boulder shale. Unlike the sandstone-capped dolerite of Springbok Vley, it is not covered by a layer of weathered rock, but crops out in large rounded blocks loosely piled together like the granite and porphyry blocks in the kopjes of Upington Common and Koras. The weathered material has evidently been washed and blown away. The rock (1829) is a coarse olivine-dolerite. The olivine is abundant in large irregular grains, partly serpentinised. The augite is the usual very pale brown variety in large irregularly-shaped ophitic masses relatively to the felspar, labradorite, and it also encloses olivine. There is a considerable amount of magnetite and a very little red biotite.

On Opdam and the southern part of Onderste Narougas there are three outlying masses of dolerite like that of the Lang Vley beacon hill, and on the west side of the pan there is a long thick dyke-like mass terminating in a high kopje westwards, but the dolerite at the west end seems to be the remnant of a sheet.

Between the north side of Uitzak and Schepkolk there are many outcrops of a sheet overlying the shales just above the Dwyka shales with boulders. In the Eierdop hills a band of arkose, five feet thick (see p. 80) lies immediately below the dolerite. The dolerite at Uitzak krantz is over 40 feet thick, and in the Eierdop hills more than 50 feet. The prominent hill called Buiskop is an outlier of apparently the same sheet, but between the Eierdop dolerite and Buiskop there are outcrops of dolerite on the low ground, and these probably belong to a lower sheet lying at the top of the massive tillite, some 80 feet below the top sheet. This lower sheet is exposed again between the Eierdop hills and Haakschein Vley. In this area, where the dolerite forms bold outstanding ridges and also occurs on low ground, the contrast between the appearance of the rock in the two situations is very striking. The dolerite of the hills forms large rounded masses, with a very dark brown or black polished exterior; these are in contact with each other at a few points only, the interstices being either free from weathered rock or filled with brownish crumbling weathered dolerite. The dolerite on low ground has a more or less deeply weathered surface, and fresh specimens are difficult to obtain, though the low outcrops are occasionally marked by the occurrence of black boulders, the kernels of partially-weathered blocks. The explanation of this difference seems to be that on steep hills, such as Eierdop and the Lang Vley Kopje, the wind and rain have almost completely removed the products of weathering, leaving the sound kernels of the great blocks bounded by joint-planes

exposed. On the flat ground the decomposing debris cannot, as a rule, be removed faster than the drainage of the area permits; the wind alone cannot move many of the loose particles, and part of every fall of rain is retained in the accumulating debris and furthers decomposition. In the course of time such low-lying masses become more exposed to denudation, and then the sound kernels are left behind on the removal of the debris by wind and rain.

In the great pan on Kopjes Kraal and Wind Hoek there are two narrow ridges traversing the pan from one side to the other in a north-north-westerly direction and about 150 yards apart. The south-western dyke is 60 feet wide, and the north-eastern 47 feet wide, about a mile from the south-eastern end. The dykes are remarkably straight, though their course does not coincide with that of joints in the rocks penetrated at the surface—Zwart Modder beds. The dykes have a W. 30° N. course, and the only two noticeable joint systems run W. 20° N. and S. 10° W. The central portions of the dykes are deeply weathered, and the marginal rock, finer in grain, has withstood the action of the weather better than the coarser interior, so the two dykes have the form of troughs standing some 15 feet above the pan floor. The shale within a few inches of the dolerite is hardened, but the rock presents no other peculiar features to the naked eye. Thin sheets are given off from the dykes, and can be followed for some feet between the shales. Thin slices were cut from a 10-inch sheet (1833), and from the fine-grained marginal rock (1834). The rocks are of quite the same character. They are made up of small felspar laths, grains of calcite, flakes of a serpentinous mineral, magnetite grains, and some larger felspar crystals, labradorite. No augite or olivine are visible, but there are some rhombic pseudomorphs of calcite and magnetite, which look as if they represent olivine.

Traversing the Zwart Modder beds of the Sannah's Poort hills there is a dyke of dolerite about 800 feet thick, which was seen taking a north-north-easterly direction for some six miles from the German border.

No dolerites were met with in the Kuruman River or the Molopo, nor were boulders of that rock seen amongst the material thrown out from the wells along those river beds.

## Blue-ground Pipe.

On the farm Witkop, in Gordonia, the existence of a serpentinous breccia of the "blue-ground" or kimberlite type has been proved in several prospecting holes. The rocks exposed at the surface round the prospecting holes are hard calcareous gravels and boulder beds of the Dwyka series, but the holes were dug in a pan-like expansion of a shallow dry valley running eastwards towards the Hygap, immediately below the dam east of the main road through the farm. Yellowish decomposed kimberlite con-

taining garnets, ilmenite, and diopside was met with from three to four feet below the surface, under the shelly limestones, gravels, and diatom earth described on a later page.

The kimberlite area is certainly over 100 yards in diameter, but its limits and shape are not known.

From two holes unweathered rock of the "hardibank" type has been taken, and three slices have been cut from specimens of this rock. One of them (1811) has a ground mass made up almost entirely of calcite, containing iron ores and perofskite. The iron ore is often in octahedra, and this is certainly magnetite, but there is also much irregularly-shaped material, which is perhaps ilmenite. The perofskite is in larger crystals than is usually the case in the Kimberley rocks; they are brownish in colour and the larger crystals are doubly refractive in part, the colours between crossed Nicols are grey-blue; the crystals do not behave uniformly throughout each individual. Crystals and fragments of crystals of olivine lie in this matrix; they are altered into greenish serpentine along cracks, and there are magnetite grains in the serpentine. The olivine is usually cleaved much more regularly than, for example, the same mineral in the olivine-dolerites of the Karroo. Irregular cavities in the section are filled with calcite and serpentine. The second section (1812) is very like the first, but it contains a few flakes of very pale biotite and rounded pieces of ilmenite, surrounded by adherent crystals of perofskite. The third slice (1813) shows a similar matrix, but in addition to the isolated olivines, there is a fragment of garnet-diopside-olivine rock; the garnet is changed round the periphery into a semi-opaque weakly birefringent substance, kelyphite; the diopside is very pale green in thin section. This rock fragment does not contain perofskite.

From the blue-ground and the yellow-ground thrown from the prospecting holes, I picked out lumps of dolerite, quartzite, red jasper, diabase or epidiorite, and pieces of Dwyka mudstone; also a fragment of a curious rock from which a slice (1827) has been cut. This rock is made of long blade-like areas of alteration products, including carbonates and a chloritic mineral, set in a ground mass of long radiating aggregates of colourless minerals, some of which is certainly quartz, and others seem to be felspars in an unusual form; there are also many very small aggregates of a highly-polarizing mineral, probably a carbonate.

## Recent and Sub-Recent Deposits.

Throughout this district superficial deposits of various kinds, and often of considerable thickness, lie above the different formations described on the previous pages. They are of importance from the economic and the purely scientific points of view, for they often hide underlying rocks completely, and give the country a character quite different from what it would have were they not present, and they contain the evidence from which the

history of Central South Africa during an unknown length of time may eventually be read. At present very much remains to be found out, both about the conditions under which some of the deposits were formed and about the circumstances which governed certain changes in them.

As a chronological classification of these rocks cannot yet be given, they may be described under broad lithological groups, which, however, cannot be sharply separated from one another in practice. The groups are:—

1. Sands, etc.
2. Gravels.
3. Limestones, siliceous, and ferruginous rocks.

### *(1) Sands.*

Nearly all the flat and gently-undulating ground in the district is covered with sand. Only along the Orange River and in the tract of country between the German border and the Hygap are there considerable stretches of hard ground on which the rocks frequently crop out; in the country just east of the Inkruip range there are also long strips of fairly hard ground, with occasional patches of surface limestone.

The country east of the Hygap is almost entirely covered with sand north of the Grond Neus stream and as far east as the Karree Boom hills on the south, the Kuie rocks further north, and the Kuis outcrops on the Molopo. This great stretch of sand is difficult to traverse, and during last year I skirted it only. From information given by a few people who have been through it, the course of the sand hills seems to be chiefly between north and west. From the Kuruman River I made several short excursions southwards, and after leaving the few irregular sand dunes near the river, where they generally lie roughly parallel to the river, the dunes have a course between W.N.W. and N.N.W. North of the Kuruman River, east of Matlapanin, the sand becomes flatter, and the low dunes are impersistent and apparently have no common trend. The Kuruman River itself is free from continuous stretches of sand, though it is occasionally invaded by small tongues of red sand, extending from high sand hills on the banks. The river bed is made of loose sandy limestone or white calcareous sand, entirely different in appearance from the red sand of the country to the north and south.

West of the Hygap the sand is broken up by many stretches of hard ground, but the wide belts of sand dunes near Abiam and between Springbok Vley and Middle Post make the road to Rietfontein a notoriously bad one to travel over.

Throughout this region the sand has a reddish tinge, owing to the presence of a small quantity of iron oxide; where the red sand reaches a river bed and becomes mingled with calcareous matter, it loses its red colour, and the same thing happens when

it forms part of the floor of a pan. Even in the harder floors of the "straate," the depressions or troughs between great dunes, the colour of the sand is often much paler than in the dunes themselves. In all these positions, the sand sometimes becomes wet, and remains so, for perhaps a considerable number of days or weeks; the bleaching is without doubt due to the reduction of the ferric hydrate in the presence of organic matter, chiefly plant remains.

In the case of some dunes west of Bloemfontein and near Skuynskalk the highest crests reach a height of quite 100 feet above the depressions on either side, but usually the height is less than 100 feet. The dunes in any particular neighbourhood may keep a straight course for many miles, but more often neighbouring dunes meet at low angles and branch again.

The dunes lie more or less parallel over considerable areas, but in the proximity of river courses, large pans, and hills, their course changes irregularly. Along rivers they often take a course more or less parallel to the bed. On the east and north side of the great Haakschein Vley the dunes are parallel to its edge, but the west side is free from sand, and the southern side nearly so. On the flanks of the hill ranges and isolated hills the sand is usually piled up to greater heights than it reaches elsewhere in the neighbourhood, but in several cases, as on the eastern side of Scheurberg and some of the Korannaberg hills, a high dune is separated from the hill by a deep trough.

East of a line joining the Kuie rocks and Karreeboom, the surface of the sand is less uneven than west of it. Though there are numerous short dunes, the sand tends to form very broad ridges, "bults," rather than well-defined dunes.

In the north-eastern part of the district, between the Kuruman River and Heuning Vley and Morokwen, the sand, though evidently of great depth and of the same nature as in the Kalahari, forms very extensive flats or gently undulating plains without dunes. In this part of the area there is also more bush and a more luxuriant growth of grass than to the south-west.

Throughout the district the sand is generally well covered with vegetation. It is only where tongues of sand stretch from the sand-veld down to the Orange River or the Molopo and Kuruman River that considerable expanses of bare sand are seen. The patch of bare sand round the outcrops of Witsand, described in last year's Report,[1] seems to be the only one of the kind in the southern Kalahari. Grass is less abundant on the sand near the German border than further east, and it seems to be generally more plentiful as one travels northwards and eastwards, as is also the case with the bush. The bush is thickest between the Mashowing River below Madebing and the Molopo, and

---

[1] Ann. Rep. Geol. Comm. for 1906, pp. 22-23. During a halt at Witsands in 1907 many pieces of the glass tubes, fulgurites, were found at Witsands, but they were all loose fragments.

there are many patches and belts between Morokwen and the Heuning Vley hills. West of Madebing the thick bush is confined to the banks of the Kuruman River, but scattered trees, especially the camel-thorn and 'Wit-gat" tree, occur throughout the sandy country traversed.

The most important effect of this vegetation, grass and bush, is to keep the sand in its place. It is evident to any one who travels through this country that, excepting the very small strips of bare sand mentioned above, the existing long and short sand dunes have long been in their present positions. Trees and stout bushes are found both in the troughs between the dunes and in various positions on the slopes and tops of the dunes themselves, so that in very many cases no considerable shifting of the crest of the dune can have taken place during the life of the tree. Near the German border the crests are sharper and have less vegetation than elsewhere, but even here the condition of the dunes is far more stable, as shown by the thickly-scattered tufts of coarse grass, than is the case with the white sand patches of Witsand and certain places along the south and west coasts of the Colony. During my journey the only places where the sand and dust were considerably disturbed by the wind were the flat ground near the Orange River and Haakschein Vley, where the size of the particles is smaller on the whole than in the sand veld itself, and where there are long stretches of ground almost or quite lacking vegetation.

The sand is chiefly made of quartz, but felspar grains seem to be very widespread. The grains are not markedly rounded, though the sharp edges have been somewhat worn down. Fragments of rock large enough to be recognisable as such are extremely rare throughout the sand-veld, except in the immediate neighbourhood of hills, and in a few places where surface limestone crops out in the sand. Even near hills like the Korannabergen, fragments of the rocks are confined to a zone a few hundred feet wide at the foot of the rock slopes, which invariably rise very steeply from the sand.

It is very difficult to get information as to the thickness of the sand. Such wells as have been dug are either in the laagtes or on patches of hard ground. On Pepani, south of Morokwen, three wells give information on this matter in an area which is outside the Kalahari proper, but which resembles the latter in several respects. The well near Mr. McKee's house is 131 feet deep, and the solid rock was not reached. The material thrown from the well is partly a pale loose sandstone, which crumbles readily; it shows no sign of stratification, but is traversed by numerous branching tubes, apparently formed round plant roots. This partly consolidated sand is associated with much loose sand and a small amount of harder material which occurs in irregularly-shaped lumps. From a piece of the harder rock a section (1849) has been cut; it consists of sub-angular grains of quartz, felspars, micropegmatite, tourmaline, magnetite, zircon,

and chert, cemented together by isotropic opal. The sand grains are evidently chiefly derived from granitic rocks, which underlie the sand in this neighbourhood. The hard rock differs from the other silicified surface rocks found during the journey in having no chalcedony in the matrix; all the silica of the matrix is still isotropic. There was not enough limestone at this place to attract attention, and the rocks collected do not contain enough carbonate of lime to give off a perceptible amount of gas when placed in acid. There are two wells in the Pepani laagte on the same farm; in the upper well 50 feet of loose sandy material of the same nature as that in the well near the house were passed through before the granite was met with; and in the lower well, about a mile below the first, 130 feet of the partly-consolidated sand were sunk through. The sandy material from these wells is just like the softer part of the rock near the house; it is traversed by the branching holes, which are sometimes slightly iron-stained, and no lamination is visible. No gravelly rock was met with in the laagte; the sand in the upper well rests directly on rotten granite, and in the lower well bed-rock was not reached.

It seems probable, that the sandy material overlying the granite on Pepani is the result of long-continued accumulation of sand on the surface of the ground, and that the level of the surface has been raised 130 feet by that process.

### (2) *Gravels and Alluvium.*

Gravels are not frequent in this area. From the north side of Upington Commonage, as far as Rietfontein, many of the patches of hard ground are thickly covered with pebbles and boulders, and appear, therefore, to be gravel, but these fragments have weathered out from the Dwyka tillite. The true gravels are confined to the river beds and their immediate neighbourhood.

Along the Orange River thin layers of gravel cover the ground in places up to 150 feet or more above the river. Thick layers are not exposed, and in many places it is obvious that the bed-rock is not deeply buried. The thickest gravel seen was in a ravine section on Kheis, which showed six feet of gravel with a loose limestone matrix. The pebbles in the gravels are chiefly of local origin, Kheis quartzites or other rocks according to the situation, but there are always many from the country above the Langebergen, Matsap and Griqua Town rocks especially. Below the outcrops of the Koras beds boulders and pebbles derived from the Koras conglomerates (purple amygdaloid and red porphyry) are very conspicuous.

There are stretches of alluvium at many places between Kheis and Upington, on the north or right bank of the river. Near Upington water is taken over the alluvium by a long furrow, and the gardens there are noted for their fertility. The alluvial deposits are confined to a narrow belt, for the river has a rather

steep fall in this part of its course, and the solid rocks crop out either on the bank or within short distances of it. The dry climate of the district, however, gives great importance to the alluvial ground within reach of artificial irrigation from the river.

In the Hygap valley below Zwart Modder there are thick layers of gravel from 20 to 30 feet above the present stream bed. The valley here is from 1,000 to 1,500 yards wide, and is limited by steep cliffs of the Zwart Modder series. The gravel is exposed in places to a depth of 20 feet. It is made of well-rounded pebbles of various rocks, evidently derived in great part from the Dwyka series, with a sandy calcareous matrix. In places the matrix is quite hard, and the rock becomes a conglomerate with limestone matrix.

The limestone cliff on the left bank of the Molopo at Zoutpans Puts (five miles below Lieutenants Pan) do not contain any gravel, though a few scattered pebbles occur in the limestone.

No gravel was seen in the Witdraai well, nor in two other dry wells in the lower part of the Kuruman River; the first gravels met with on a journey up that river were seen about 35 miles from its confluence with the Molopo, where a calcareous conglomerate with pebbles of chalcedony, quartz, red jaspers, banded magnetic jaspers, chert, and lavas from the Ongeluk series, forms the river bed in places. The limestone matrix of this consolidated gravel is just like the white surface limestone exposed very frequently on the banks and in the bed of the river.

At Witkrantz there is a well, 35 feet deep, in the bed of the Kuruman River; the well is sunk through sandy limestone, with occasional layers of pebbles of the same kind as those mentioned above from the calcareous conglomerates lower down the river. The bed rock has not been reached in this well.

On the Mashowing, 16 miles above its junction with the Kuruman River, gravels appear on the surface some 50 feet above the bed; they consist of fragments from the middle and lower groups of the Griqua Town series. In places they are cemented together by a limestone matrix. These rocks are again found in section on the steep slopes on the sides of the Mashowing and Kgogole at Madebing, and at places the fragments are angular. The limestone has here undergone more or less silicification, and will be referred to again.

### *(3) Limestones, Siliceous, and Ferruginous Rocks.*

Surface limestones of various kinds are found in all parts of the district under consideration, though in the sand-veld considerable intervals may separate the outcrops. The surface quartzites, on the other hand, were only found in the north-western part of the area, betwen the neighbourhood of Genesa and that of Kuis; they were not met with in the Kuruman River

below Tsenin or in the sand-veld south of the Molopo and west of the Korannaberg.

All these rocks are essentially the result of the cementation of sand by carbonates or silica, with or without an appreciable quantity of iron oxide, but while some of them have been formed directly by the deposition of the carbonates or silica around the sand grains, others are evidently the result of a subsequent replacement of the earlier carbonates by silica.

A precise sub-division of these rocks according to their modes of origin cannot yet be made, nor can they be classified according to age.

In many parts of the district there are more or less extensive deposits of whitish limestone, containing grains of sand and fragments of rock. In the country between Morokwen and the Heuning Vley hills these limestones are particularly abundant, just as they are further south in Kuruman and Griqualand West, on the continuation of the same belt of country formed by the Campbell Rand series. In this area the surface limestone is obviously formed by deposition from water rising to the surface and evaporating there, leaving behind the material carried up in solution from the underlying Campbell Rand limestones. The outer crust is generally distinctly harder than the rock beneath it, and the limestone encloses more or less sand and, occasionally, pieces of chert.

In no other situation, except along the river beds traversing the sand-veld, is so much surface limestone seen as on the Campbell Rand beds.

This kind of surface limestone crops up very frequently between Morokwen and Konkwe, but west of Konkwe the outcrops become less abundant, and in parts of the area between Konkwe and Heuning Vley nothing but sand is seen for many miles together. Where the Mashowing traverses the Campbell Rand beds, the sand is also very prevalent; the turfaceous limestone outcrops are confined to a belt near the river.

The rivers which enter the sand veld from the east, *i.e.*, the Molopo, Kgogole, Mashowing, and Kuruman, all traverse the Campbell Rand beds before reaching the sand veld, and therefore, whatever water flows down them from behind the Heuning Vley-Kuruman hills brings some limestone in solution. Wherever the banks of these rivers are not covered by sand, some limestone is seen, and usually it is the only hard rock exposed.

The sections along these rivers will be described separately.

*The Molopo.*—The only part of this river examined above its junction with the Nossob was the 12 miles between Kolingkwane and Kuis. Approaching this part from the south, one travels over a sand-covered plateau, on which the sand forms irregular undulations, but not the long dunes characteristic of

the Kalahari south of the Kuruman River. Outcrops of surface limestone are first seen from two to three miles south of the Molopo, and they become more frequent towards the edge of the steep slope which bounds the river. The descent from the plateau to the river bed is very steep, usually steep enough to be called a cliff, and good sections are frequently exposed. Fig. 11 represents a short length of the cliff on the left side of the river near the Mogogobe water-hole. The Matsap quartzites here form the base of the section, and they are overlain, first by a few inches of quartzite rubble, and then by 90 feet or less of various limestones and siliceous rocks. The only indication of bedding is given by the layer of gravel, which has a maximum thickness of 12 feet here, but which thins out. Some hundreds of yards down the valley a similar gravel fills a hollow in the Matsap beds, and is covered by limestone. The pebbles in the gravel are of various rocks, chiefly from the Griqua Town and Campbell Rand beds, but also quartzites from the Matsap and a few granites and amygdaloids of the Pniel type, both of which may perhaps have come from the Dwyka in the immediate neighbourhood. The matrix of the gravel is mostly compact, sandy limestone, but there are patches of silicified rock which stand out more or less prominently from the limestone on the exposed surface. The silicification appears to have taken place capriciously, partly along narrow veins in the limestone, now filled with chalcedony, and partly as a general replacement of the carbonates by silica. In appearance there is very little or no distinction between the limestone and the silicified rock as seen by the naked eye; they have to be scratched or hit with a hammer to be distinguished. The thick mass of almost structureless sandy limestones forming the greater part of the cliff has a pinkish colour below and a yellowish or white colour above. The pink rock in places forms large rounded masses in the white limestone; one of these lumps at first looked as if it were a boulder derived from the pink rock; a careful examination of several such masses showed that they were not of that nature, but that they are masses of limestone slightly different in colour from the enclosing rock, but not sharply separable from it. Siliceous masses of a whitish colour frequently occur in the upper 30 feet of the section; they are irregular in shape and do not have sharp boundaries. The limestone in their vicinity is traversed by thin veins of chalcedony. Thin sections of these rocks have not been prepared, for the rocks are very like those described below from a similar position in the Kgogole laagte near Madebing. These silicified rocks were not seen near the base of the superficial deposits, though on account of the short time spent at the locality this fact does not imply that they never occur there.

Throughout the limestone grains of sand are frequently seen; in the harder parts the rock breaks through the grains rather than round them.

The uppermost few feet of the section are harder than the

rock just below, and on the steeper parts of the cliffs many irregular caves are formed on that account.

The Mogogobe section is typical of the Molopo valley between

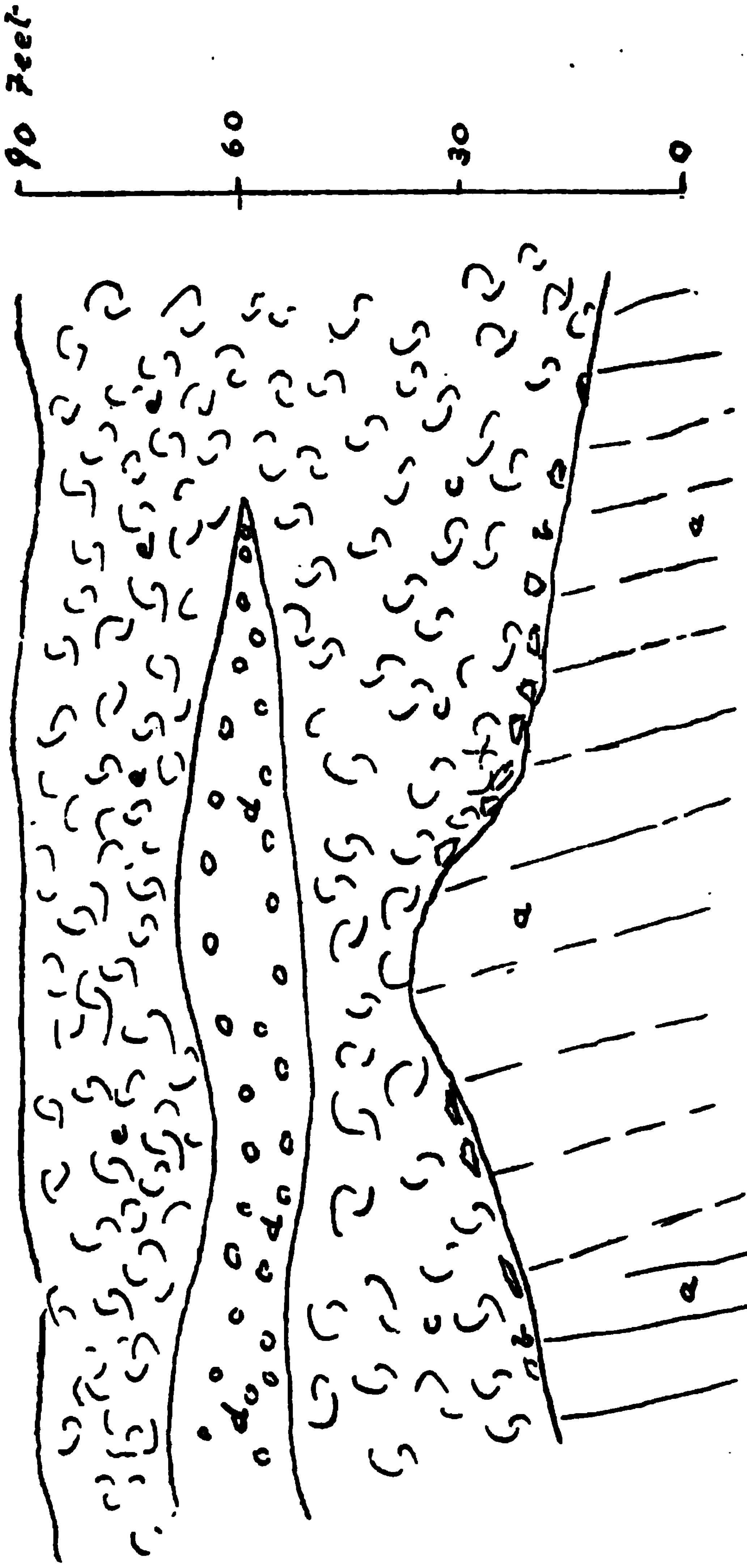



FIG. 11.—Section seen at Mogogobe on the left bank of the Molopo. *a*, *a*, purple Matsap quartzites dipping west; *b*, *b*, rubble of quartzite with loose limestone matrix; *c*, *c*, pinkish limestone with occasional pebbles; *d*, conglomerate with limestone or chalcedony matrix: the limits are not really so well defined as in the sketch *c*, whitish limestone with large masses of chalcedonised rock.

Kolingkwane and Kuis, though the details vary. In places the hard Matsap quartzites rise nearly to the top of the cliff, and are overlain by only a few feet of limestone. Generally the superficial rocks are thicker where they overlie the Dwyka than where the Matsap beds crop out.

No fossils were found in the limestone of the cliffs, though some small snail shells and pieces of bone occur in the gravelly limestone exposed within the valley near the level of the top of the water-hole.

The sections on either side of the valley and some 500 yards apart are very similar, but this does not involve the assumption that the deposits exposed once stretched across the valley and have since been cut through by the Molopo. It is more likely that the hardening materials have been formed continuously within the sand or gravel forming the bank at any particular time, and that the steepness of the cliffs is due to the top hard layer, which always caps the limestone, protecting the immediately underlying rock during the continual backward cutting of the cliff by wind and rain. I looked for a suitable side ravine, which might afford a lengthy section of the superficial deposits at right angles to the river valley, but I did not find one. There are several short steep ravines, but they are covered with loose fragments of limestone, and do not give the required information.

Near the bottom of the valley there are frequent exposures of gravel with limestone cement and of sandy limestone. These exposures are small, but they show bedding; layers of gravel are intercalated with layers of more or less sandy limestone; a thick section of these rocks would present a very different appearance from that of the cliff at Mogogobe.

## *The Kgogole River.*

The Kgogole River rises south-west of Genesa on a sand-covered granite plateau, and after being joined by the Mokgalo laagte enters the Mashowing at Madebing. A short part only of the valley has been examined.

Near the Kgogole Reserve, on the granite region, no limestone is seen on the banks of the laagte, but quartzites and ferruginous rocks crop out along some four miles of the right bank about 40 feet above the floor of the laagte. They are whitish and yellow-brown stained cavernous rocks with a maximum exposed thickness of four feet. The varieties richest in iron occur at the base of the exposures, but there is a very gradual change from the darkest to the lightest coloured rocks, which are found at the top. The rock is a quartzite, white, yellowish, or brown, traversed by irregular cavities, which are lined with chalcedony, opal or a thin layer of iron oxide, and when freshly exposed by being broken through, sand falls from them. In places a roughly parallel structure is given to the rock by the cavities being arranged with their longer axes lying nearly flat, but it is a very indefinite structure. The rock passes under sand a few yards away from the top of the steep slope to the laagte. No quartzite was seen in a corresponding position on the left bank of the laagte. No limestone appears at the surface near the

quartzite, but some soft limestone is thrown from a well in the laagte in which granite is exposed, and a small amount of limestone occurs in thin layers between shells of weathered granite in a shallow ravine on the left side of the laagte, where there is no quartzite.

At Tlaping, in the Mokgalo laagte, soft shelly limestone (with *Physa*) is taken from a well, and fragments of the usual hard surface limestone are found on the surface north of the laagte together with pieces of surface quartzite like that near Kgogole, but exposures of the latter rock were not found.

In the Kgogole laagte about half a mile above its junction with the Mashowing there are good exposures of the limestones and quartzites on the left side of the valley. They are interesting also, because it is obvious, from the position of outcrops of the solid rocks here (Ongeluk volcanic series), that the super-

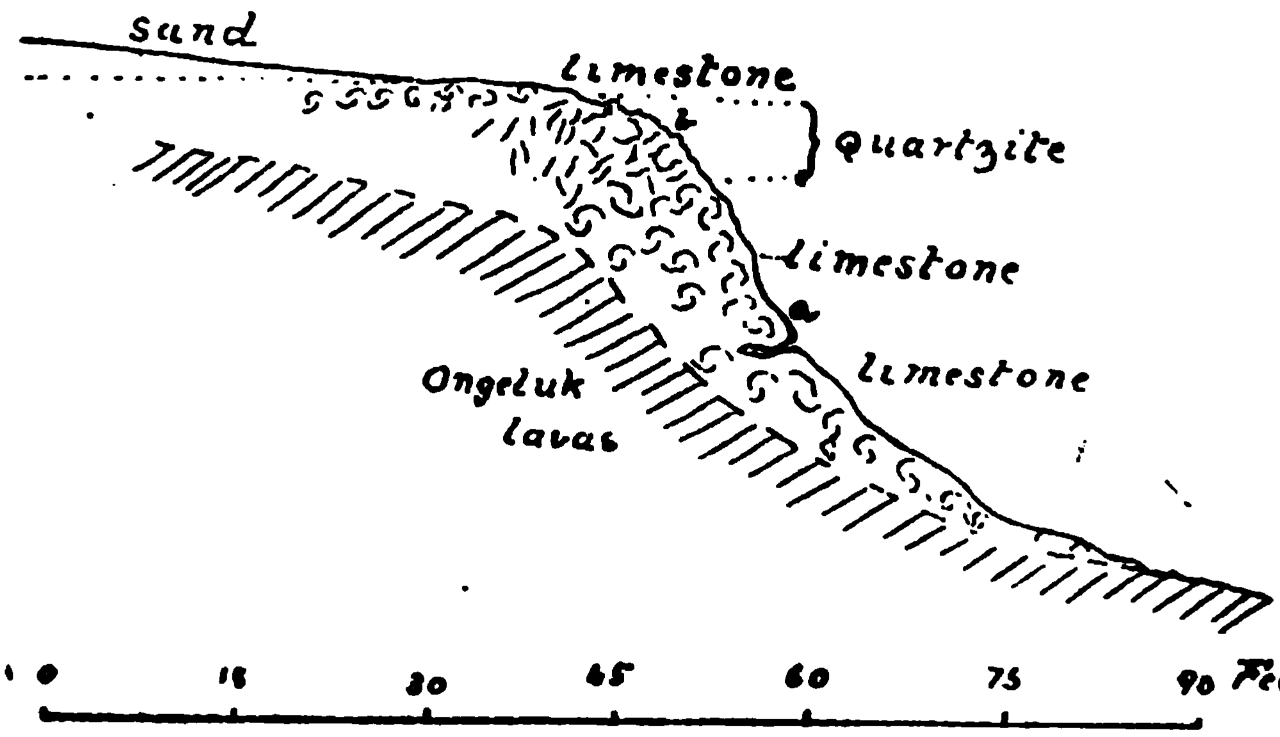



FIG. 12.—Section on left side of Kgogole laagte half a mile above its junction with the Mashowing ; *a* and *b*, spots from which the rock slices, 1837 and 1838, were taken.

ficial deposits are merely a thin coating laid over the rock slope, as represented diagrammatically in fig. 12. The outline of the solid rock there given is not observable in section at any one place, but from the position of outcrops on the same side of the laagte within a few hundred yards of the locality it is certain that the outline fairly represents the facts. The Ongeluk rocks are exposed at the foot of the slope and they are overlain by limestone containing numerous fragments of lava and vein quartz. The lava fragments are weathered, the outer zone is red to a depth of nearly half-an-inch in some cases, within this the rock is bluish green. The breccia is continued up the slope for some 10 feet, when the fragments become scarce, and the rock is a sandy limestone of various degrees of hardness; the softer parts have, in places, been removed, giving rise to holes. A thin slice (1837), taken from a rock just above the hole shown in the section, fig. 12, is seen under the microscope to consist of grains of quartz and a few small pieces of Ongeluk lava, set in

a rather coarse-grained calcite matrix. In a few places a small amount of chalcedony is seen between the crystalline particles of calcite. The chalcedony in this rock is not present in sufficient quantity to be observed by the unaided eye, but the amount increases upwards until the rock appears to contain no carbonates. The quartzitic rock proper occupies a vertical height of about 10 feet on the slope, and is covered by surface limestone, which soon disappears under sand. The upper limit of the quartzitic rock is more sharply defined than the lower, but there is a gradual transition between it and the overlying limestone. Two slices were cut from the quartzite (1838 and 1851). They are crowded with sand grains, chiefly of quartz, with a few felspars and other minerals, including a grain of tourmaline. These lie in a matrix of small grains and rhombohedra of calcite and much silica. The calcite is mostly packed closely round the sand grains and then follows opal, chalcedony fills the remaining part of the interstices. A large patch of chalcedony encloses a central coarsely-crystalline area of calcite. Some patches are coloured brown by iron oxides. Another slice (1839) from the quartzite near the place from which the other two were taken consists of sand grains cemented by opal and chalcedony, and part of a pebble of chert, with pseudomorphs after a cubic mineral.

These silicified rocks seem to have been formed by the replacement of limestone cement by silica, which first has the properties of opal and subsequently changes to chalcedony. It is quite clear that all stages of the replacement are found within a short distance of each other in one and the same rock mass. It would be important to find out in this or a similar locality whether a section taken, say, 200 feet behind the slope, under the sand, shows a similar set of changes in the rocks lying upon the Ongeluk beds. At present there is no opportunity for such an observation. The partly silicified rock at this locality is very like a rock mentioned by Dr. Passarge from the bottom of the water-hole at Inkauani Pan[1], and which he calls "hard chalcedony-sandstone," and says it may be either a directly silicified sandstone (eingekieselter sandstein) or a silicified calcareous sandstone (verkieselter kalksandstein). A slice from a specimen of this rock (1861) given me by Prof. Kalkowsky is very like (1838) described above from the Kgogole laagte.

## *Matamatobo Laagte.*

No outcrops were met with in the short section of this laagte, which I examined. The floor of the laagte south of Pepani is a firm grey soil; small pieces of loose textured limestone are thrown up by burrowing animals. Surface limestone is exposed

[1] "Die Kalahari," p. 518.

by rain washing out the wagon track in the tributary laagte from the S.S.E. which leads to the Kgogole Reserve.

On the farm Shooter's Hill there is an exposure of ferruginous and siliceous rock at the junction of two branches of the Matamatobo laagte. It is a reddish earthy rock with irregularly-shaped masses of harder material, due to cementation by iron oxides or silica, or both. There are irregularly-shaped cavities in some of the hard masses lined with opal. The mineral fragments enclosed in the earthy or hard matrix and large enough to be recognised with the help of a lens are quartz.

*The Mashowing River.*

The first superficial deposits of interest in the Mashowing Valley are seen near Masilibitsani. The bed rock here is granite or gneiss, which crops out frequently in the river bed and on the flat or gently-sloping plain to the north and south of it. To the south of the river the granite disappears under sand; along the river, as far down as the Black Reef escarpment of Garaphoane, sand is the prevalent covering on the south side, and there are very few outcrops of limestone. To the north of the river opposite Masilibitsani there is a mile-wide slope of surface limestone and gravel, broken only by a few large outcrops of granite and quartz-porphyry; the limestone slope rises to about 40 feet above the river, when it is succeeded by a steeper slope of limestone and a krantz of the same rock, 10 feet high, above which lies a low krantz of quartzite without pebbles, and this quartzite passes under sand. The section in Fig. 13 represents the facts at this locality. The river bank in places is a vertical surface of

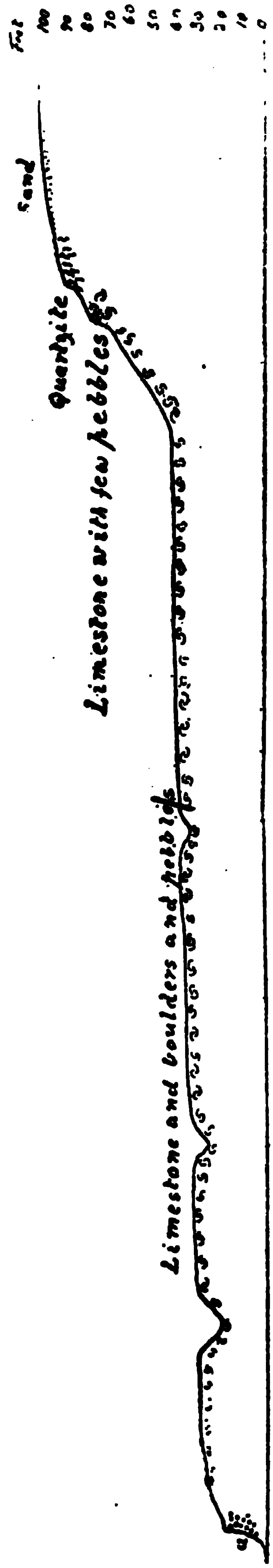



FIG. 13.—Section across the flat north of the Mashowing, near Masibibitsani. *a*, Gravel with loose limestone matrix seen on the river bank. Length of section, 1 mile.

gravel with a loose sandy limestone matrix. The limestone on the slope above contains boulders and pebbles of Black Reef quartzite, granite and gneiss, quartz-porphyry, diabase, and amygdaloidal lava, but not of the surface quartzites such as are exposed to the north; fragments of these quartzites are only found on or at the foot of the steep slope between the outcrop and the plain. The plain is cut up by ravines, in which sections through the limestone with boulders are exposed to the depth of about 10 feet. So far as observed, no silicification has taken place in these limestones, but they have not been minutely examined. The limestone of the steep slope contains a few pebbles. The passage upwards into the quartzite is obscured by debris, and by the fact that both the limestone and quartzite are much harder outside than within; in each case after breaking away the outer hard blocks near the limit of the two, one finds a loosely compacted sandy material, apparently without much lime in it and probably no siliceous cement. The quartzite outcrops are very cavernous, and are like the rock described below from the Genesa laagte. The outcrops extend nearly 12 miles down the right side of the valley, but they disappear below the sand before the Black Reef escarpment on Garaphoane is reached. Quartzite of the same kind and in a similar position reappears on the right bank on the west side of Garaphoane, and extends 12 miles down the river as far as the Magonat Reserve. The ground between the quartzite outcrops and the river bed is occupied by limestone and gravel, as at Masilibitsani. The limestone becomes of importance on the left or south bank some eight miles below Garaphoane. It extends from the bed of the river to a height of 50 or 60 feet above it, but there are no definite layers or isolated outcrops of quartzite at this level on the left bank, though a quartzite like that above Garaphoane appears at the surface about a mile south of the river on Pietquane, and is soon lost under sand. Both on the right and left banks irregular patches and layers of siliceous rock of a different type from the top quartzite occur in the tufaceous limestone exposed in the banks and on the slopes above them below the Linopen Reserve. These rocks are found at short intervals many miles down the river, to within 16 miles of its junction with the Kuruman River, *i.e.*, over more than 50 miles of its course. A thin slice (1731) from the farm Olney, on the south bank of the Mashowing, together with notes made in the field, affords the following description of the silicified rock. The rock is largely a very fine-grained limestone, containing a few grains of quartz. This compact limestone has been divided up into various-sized pieces by cracks running in various planes, but the largest and most persistent cracks are roughly parallel to the upper surface of the rock, *i.e.*, to the surface of the ground. These cracks are filled with calcite, or silica, or both, and they give the rock a brecciated appearance. The minerals filling the cracks were first deposited uniformly on the walls, and the successive layers conform to the

irregularities of the walls; but where the cracks are more than 2 mm. wide, part of the space is filled with material deposited without reference to the shape of the walls. Generally the smaller cracks are filled with calcite alone, but there are small cracks, less than 2 mm. long, entirely filled with chalcedony, or first by a layer of opal and the rest by chalcedony. The opal evidently changes to chalcedony, for cracks looking precisely alike are found in the one case to have an outer layer of opal, and in the other to consist of chalcedony alone. In a few cases the larger cracks are filled with calcite alone, generally with a mixture of calcite and chalcedony, and again with chalcedony alone. The calcite in this mixture does not occur in small crystals, but in irregularly-shaped crystalline grains of large size, very much larger than in the limestone itself. In certain irregularly-shaped areas of considerable size there is a mixture of chalcedony and calcite grains of very small size, like those of the limestone. These areas are in part sharply bounded and in part grade into a transitional rock, with more calcite and less chalcedony; this transitional rock passes into the ordinary limestone. In these areas we see stages between the limestone and an almost completely silicified rock.

On the Mashowing at Madebing a curious breccia partly covers the outcrops of the Ongeluk volcanic rocks on the steep slope above the river, on its right bank. In one place 10 feet of the breccia were seen in section. It consists of fragments of quartz and volcanic rocks set in a sandy siliceous and ferruginous matrix; most of the iron is in the form of limonite, but haematite is frequently seen. Some of the breccia is clayey and soft.

On the left bank about four miles below Madebing there are good exposures of limestone and silicified rock. In general, they resemble those in the cliffs at Mogogobe and in the Kgogole laagte at Madebing. The lower exposures are limestones; the silicified limestone forms an inconstant band near the upper part or at the top of the steep slope; it passes laterally into ordinary limestone, in which no silicification can be detected in the field.

### *The Kuruman River and the Matlowing.*

On the Matlowing River, near Tsenin, there are banks of white sandy limestone, 14 feet high. Silicification was not noticed in this rock, but a large block of a peculiar-looking pebbly silicified rock was found in the river bed. The pebbles are of chert, quartz, and blue dolomite or limestone from the Campbell Rand beds. In thin section (1732) the matrix is seen to consist of chalcedony and calcite. The pebbles are generally surrounded by a thin coat of chalcedony, and the rest of the matrix is chalcedony with a small quantity of calcite in rhombohedra. The chalcedony of the interspaces often has a spherulitic structure. I was unable to learn the source of this rock, but it probably came from no great distance.

steep fall in this part of its course, and the solid rocks crop out either on the bank or within short distances of it. The dry climate of the district, however, gives great importance to the alluvial ground within reach of artificial irrigation from the river.

In the Hygap valley below Zwart Modder there are thick layers of gravel from 20 to 30 feet above the present stream bed. The valley here is from 1,000 to 1,500 yards wide, and is limited by steep cliffs of the Zwart Modder series. The gravel is exposed in places to a depth of 20 feet. It is made of well-rounded pebbles of various rocks, evidently derived in great part from the Dwyka series, with a sandy calcareous matrix. In places the matrix is quite hard, and the rock becomes a conglomerate with limestone matrix.

The limestone cliff on the left bank of the Molopo at Zoutpans Puts (five miles below Lieutenants Pan) do not contain any gravel, though a few scattered pebbles occur in the limestone.

No gravel was seen in the Witdraai well, nor in two other dry wells in the lower part of the Kuruman River; the first gravels met with on a journey up that river were seen about 35 miles from its confluence with the Molopo, where a calcareous conglomerate with pebbles of chalcedony, quartz, red jaspers, banded magnetic jaspers, chert, and lavas from the Ongeluk series, forms the river bed in places. The limestone matrix of this consolidated gravel is just like the white surface limestone exposed very frequently on the banks and in the bed of the river.

At Witkrantz there is a well, 35 feet deep, in the bed of the Kuruman River; the well is sunk through sandy limestone, with occasional layers of pebbles of the same kind as those mentioned above from the calcareous conglomerates lower down the river. The bed rock has not been reached in this well.

On the Mashowing, 16 miles above its junction with the Kuruman River, gravels appear on the surface some 50 feet above the bed; they consist of fragments from the middle and lower groups of the Griqua Town series. In places they are cemented together by a limestone matrix. These rocks are again found in section on the steep slopes on the sides of the Mashowing and Kgogole at Madebing, and at places the fragments are angular. The limestone has here undergone more or less silicification, and will be referred to again.

### *(3) Limestones, Siliceous, and Ferruginous Rocks.*

Surface limestones of various kinds are found in all parts of the district under consideration, though in the sand-veld considerable intervals may separate the outcrops. The surface quartzites, on the other hand, were only found in the north-western part of the area, betwen the neighbourhood of Genesa and that of Kuis; they were not met with in the Kuruman River

below Tsenin or in the sand-veld south of the Molopo and west of the Korannaberg.

All these rocks are essentially the result of the cementation of sand by carbonates or silica, with or without an appreciable quantity of iron oxide, but while some of them have been formed directly by the deposition of the carbonates or silica around the sand grains, others are evidently the result of a subsequent replacement of the earlier carbonates by silica.

A precise sub-division of these rocks according to their modes of origin cannot yet be made, nor can they be classified according to age.

In many parts of the district there are more or less extensive deposits of whitish limestone, containing grains of sand and fragments of rock. In the country between Morokwen and the Heuning Vley hills these limestones are particularly abundant, just as they are further south in Kuruman and Griqualand West, on the continuation of the same belt of country formed by the Campbell Rand series. In this area the surface limestone is obviously formed by deposition from water rising to the surface and evaporating there, leaving behind the material carried up in solution from the underlying Campbell Rand limestones. The outer crust is generally distinctly harder than the rock beneath it, and the limestone encloses more or less sand and, occasionally, pieces of chert.

In no other situation, except along the river beds traversing the sand-veld, is so much surface limestone seen as on the Campbell Rand beds.

This kind of surface limestone crops up very frequently between Morokwen and Konkwe, but west of Konkwe the outcrops become less abundant, and in parts of the area between Konkwe and Heuning Vley nothing but sand is seen for many miles together. Where the Mashowing traverses the Campbell Rand beds, the sand is also very prevalent; the turfaceous limestone outcrops are confined to a belt near the river.

The rivers which enter the sand veld from the east, *i.e.*, the Molopo, Kgogole, Mashowing, and Kuruman, all traverse the Campbell Rand beds before reaching the sand veld, and therefore, whatever water flows down them from behind the Heuning Vley-Kuruman hills brings some limestone in solution. Wherever the banks of these rivers are not covered by sand, some limestone is seen, and usually it is the only hard rock exposed.

The sections along these rivers will be described separately.

*The Molopo.*—The only part of this river examined above its junction with the Nossob was the 12 miles between Kolingkwane and Kuis. Approaching this part from the south, one travels over a sand-covered plateau, on which the sand forms irregular undulations, but not the long dunes characteristic of

so. He remarks the presence and abundance of *Corbicula fluminalis*, a Nile species.

Herr Reichelt determined the diatoms in Dr. Passarge's specimens from the Kalahari, and 17 out of the 34 species determined from Witkop are mentioned by him in the list on pp. 770-773 of "Die Kalahari." But he states in "Aus-Namaland, etc.," p. 706, that the Witkop collection is a peculiar flora of slightly brak-water origin, and is not like any assemblage of species collected by Dr. Passarge. They do not throw any new light on the geological age of the deposit. He detected siliceous sponge spicules in the Witkop rock

The valley expands into a pan, under the sandy surface of which there is a yellowish limestone containing *Physa* shells. This is the only pan met with in Gordonia which contained fossiliferous limestone, but it differs from the typical pans in being an expansion of the old valley, and not an isolated depression. In a thin section of this rock (1826) the outlines of the shells are less obvious than in the hand specimen on account of the recrystallization of the carbonate of lime in them and to the want of clear distinction between it and the calcite of the matrix. Diatoms are abundant.

Since these fossiliferous rocks of Witkop were formed there has been no considerable change in the surface features; the deposits have neither been denuded nor buried to any noteworthy extent. The white calcareous sand found on the sides of the depression no doubt shifts from time to time, but the water brought down by the valley has not had time to bury or denude the fossiliferous rocks. There is now a dam across the valley, and, owing to the impervious nature of much of the ground above the dam, a considerable amount of water comes down during rains. It seems to me that the general features of the neighbourhood and the circumstances under which the fossiliferous deposits are found do not justify the use of the term "Pleistocene" in connection with them. Dr. Boettger is not very sure about the extinction of the mollusca, and the mollusca of Bechuanaland and Gordonia do not seem to have been fully studied as yet. The temporary existence of the great vley at Abiquas Puts and its fish in 1894 shows that the mere presence of a layer of richly-fossiliferous deposit may not indicate anything that can be properly called a change of climate.

In those parts of rivers or laagtes, surveyed during last year, lying entirely to the east of the Black Reef escarpment, the laagtes between Tlakgaming, Genesa, and Morokwen, surface limestone is often seen, though it is not developed to the same extent as in the laagtes to the west. So far as the bed rock of this district is known it is granite or gneiss, with an occasional dolerite dyke.

In a dry well, two miles below the Tlakgaming fence across the Doorn laagte, small irregular nodules of white sandy lime-

stone occur in grey sandy soil, of which there is a thickness of three feet overlying whitish granite wash. The lumps of limestone are evidently nodules formed where they are found. On Stonehenge and Distin, along the Tlakgaming laagte, surface limestone crops out on the road where the traffic has removed some of the soil, and on the south part of Distin some eight feet of soft limestone with hard portions in it are exposed in a well. The well is in the laagte. The limestone contains *Physa* shells. A thin section (1714) shows a semi-opaque base of limestone, in which no structure is visible; there are grains of quartz, felspar, and epidote, and crystalline calcite fills irregular spaces and the interior of *Physa* shells. The siliceous skeletons of diatoms are visible in places, though they are difficult to see on account of the presence of the limestone.

In a well in the Genesa laagte on Donegal, 20 feet of white sandy limestone were found to overlie the granite, and the same rock crops out at many places in the laagte between the Donegal well and the Wegdraai well. About two miles above the latter surface-quartzite crops out on the right bank, forming in places a vertical face six feet high, and extending some 200 yards back from this outcrop before being quite covered by sand. These outcrops are continued some five miles up the laagte. The rock seen in the outcrops is a quartzite penetrated by ramifying passages up to three inches wide, after the manner of the holes in a sponge. The holes are filled with sandy earth behind the face of the outcrops. In thin section (1715, 1716) the rock is seen to consist of various-sized grains of quartz, felspar (chiefly microcline), magnetite, tourmaline, epidote, zircon, and apatite, cemented by a siliceous matrix, mostly chalcedony, though some opal is present. The larger grains are rounded, the smaller more angular. Though the felspar grains are generally recognisable in ordinary light by their slight turbidity, due to alteration, they are not much altered, and some of them are as clear as the quartz. There is no limestone seen above the quartzites or on the slope down to the laagte. This rock would seem to be one of the directly silicified sandstones (eingekieselter chalcedon-sandstein of Dr. Passarge). When lumps of the quartzite are broken up, the apparently solid portions are found to contain irregularly-shaped patches and veins of bluish chalcedony; these are sometimes hollow, and in such cases there is a layer of vitreous opal on the surface of the chalcedony. Neither the chalcedony nor opal was seen lining one of the branching tubular cavities mentioned above. Towards the upper surface the rock becomes more ferruginous, and in places it is indistinguishable from the usual lateritic ironstone, *i.e.*, it is made of grains of sand cemented together by brown oxide of iron.

I could not find a well or other exposure showing the thickness of this rock under the sand of the plateau behind the river bank. In general appearance the rock seems to be the edge of a layer under the pale red sand of the plateau. Its absence from the

left bank of the laagte and from the wells on Request, though a few inches of ironstone were passed through by the upper of the two wells, would indicate that the quartzite is only an isolated patch. Its mode of occurrence on this river is like that of the surface of quartzites of the south of Cape Colony. Its variable character within short distances is also a point of resemblance to the latter rocks.

In the granite country north and east of the Black Reef escarpment, from Takoon to Morokwen, little limestone is seen outside the laagtes, though wells sometimes prove its existence where it would not be expected. On the farm Bosh Buit, between Genesa and Takoon, the decomposed granite was met with 17 feet below the surface; it is covered by 10 feet of earthy material, with some calcareous matter in it, and this is followed by four feet of sandy limestone, above which are three feet of sandy soil. The country here is covered generally with pale red sand. Where a road descends a slope towards a laagte in this region, a sandy ironstone is usually exposed by the washing away of some of the sand by rain water.

Between the Korannaberg-Langeberg ranges and the Scheurberg-Inkruip-Kuie line of outcrops, surface limestone is seen in places where the sand is absent or less abundant than elsewhere. The limestone is a sandy rock, hard with softer limestone below the surface. In places, as to the east of Inkruip, outcrops of Matsap quartzite are seen in the same neighbourhood as the limestone, and consequently the rock underlying the limestone is probably the quartzite. In other localities, as to the south-east of Gamotep, where there is much limestone, the nature of the underlying rock is quite uncertain.

In the country between the Hygap and the German border, surface limestone is frequently seen lying on the Dwyka tillite, where there is little or no sand. This limestone oftens contains pebbles and boulders weathered out of the Dwyka.

## Pans.

Pans are found in many parts of the district, but they are especially abundant in the area occupied by the Dwyka on the western border.

In the granite area of the north-east pans are few and usually small. The Klein Chwaing Pan was described in last year's Report.[1]

The pan at Morokwen is the largest that was seen in the north-east of the district. Granite crops out in the pan, and at several spots round it at a higher level than the floor of the pan. Limestone forms a bank round part of the pan, and it has undergone partial silicification; small veins and patches of chalcedony may be found on breaking open the limestone. The pan has a small quantity of salt in it mingled with the calcareous sandy

[1] Ann. Rep. Geol. Com. for 1906, p. 82.

material forming the surface of the floor. The natives collect a little salt from it.

The other pans seen in this region are small depressions in the sandy ground with a harder material on the floor than the surrounding sand.

I had an opportunity of visiting the farm Water Pan, described by Mr. du Toit in the Report for 1905, p. 156, and as the green quartzite noted by him is of considerable interest, a few more details of its occurrence and nature are worth recording. The pan itself was full of water at the time of my visit, but the quartzite is exposed in two wells. In one of these the decomposed granite is met with 20 feet from the surface, and above it lie eight feet of green quartzite with a capping of 12 feet of rather loose limestone with *Physa* and other fresh water shells. In the second well the granite surface is 23 feet down, and there are three feet of quartzite and 20 feet of limestone on the top. A thin layer of quartz and quartz-porphyry pebbles separates the limestone and quartzite. The slope of the granite surface is towards the pan. The quartzite contains pebbles of quartz-porphyry. A thin section (1844) shows chips and grains of quartz, felspar, zircon, magnetite, and chert set in a siliceous matrix, which has a yellowish tinge under the microscope. Most of the matrix is scarcely anisotropic, but parts of it are chalcedony. Much of the matrix looks as if it was made of chalcedony, of which the individual particles are extremely small. There are cracks filled with a yellow, rather highly birefringent substance with radial structure.

On the area occupied by the Campbell Rand beds, between Morokwen and Heuning Vley, there are many small pans, depressions on the surface of the hard tufaceous limestone seen so frequently in that area.

The large pan called Heuning Vley lies immediately at the foot of the escarpment of the Griqua Town series. It is about 3¾ miles long in a north-north-easterly direction, following the strike of the Griqua Town beds, and about a mile wide at its widest part. The Griqua Town beds in places descend to the floor of the pan, but do not crop out on the floor itself; they form low krantzes in the middle and southern parts of the western side of the pan, and small springs of fresh water issue from the base of the outcrops. Where there is ground higher than the floor of the pan between its western border and the outcrops of Griqua Town beds, masses of hard ferruginous breccia of fragments of Griqua Town beds are often seen appearing through the sandy soil, but no limestone was met with on the western side. At the south end of the pan, the place of the ferruginous breccia is taken by a breccia with limestone matrix; this rock is soon covered by sand. The eastern bank is sandy, with a little limestone in the southern parts. On the eastern side the lowest rock seen is a whitish limestone, which passes

upwards into a greenish quartzite. Both these rocks contain small angular and subangular fragments of Griqua Town rocks up to two inches in length. A thin section of what was collected as a piece of the limestone (1840) proves it to be mainly composed of a matrix of small grains and rhombohedra of calcite, enclosing sand grains of quartz, felspar, and tourmaline. There are small patches and veins of chalcedony in the limestone; the chalcedony preserves the outlines of some of the original rhombohedral calcite by the presence of zones of very minute opaque particles. A section (1841) from a quartzite from the same place shows rounded grains of quartz, felspar (microcline and plagioclase), chert, and an igneous rock largely made of plagioclase, set in a cement of chalcedony. Calcite is only seen in one part of the slice, where there is a small amount scattered through the chalcedony.

The floor of the pan is made of a white sandy calcareous mud, which is hard when dry, but the wind can move dust and sand from its surface, and the place is undoubtedly undergoing a gradual reduction in level owing to this action. A slight efflorescence of salts, in very large part common salt, is found in patches on the western side of the pan, and the water which gives rise to swampy areas on that side of the pan is salt, although the water which issues from the springs mentioned above tastes quite fresh.

In the middle and northern part of the pan there are many outcrops of limestone and siliceous rocks projecting above its surface. Some of the outcrops are small and isolated, but they mostly form groups from 20 to 100 yards long and of various widths of about the same extent. The rocks stand up as much as two feet from the surface, and are obviously undergoing denudation. The limestone and quartzite often occur together in one outcrop. A section (1850) from one of these outcrops shows a few quartz-grains set in a matrix of granular calcite, with small patches and streaks of chalcedony. No diatoms were seen in this or the other limestone examined from Heuning Vley, but they may be masked by the calcite, and a complete examination of the rocks has not yet been made.

Both the limestone and quartzite at the level of the floor of the pan have a green colour, which becomes brighter upwards, and the tops of the quartzite outcrops are almost white. These highest quartzites are glassy and brittle rocks, evidently containing little or no carbonate.

The eastern pan at Heuning Vley has a white calcareous sandy mud floor, without outcrops of limestone or quartzite. There are a few small fragments of limestone on the surface. It is surrounded by greyish white sand.

Between the W.N.W. dunes in the country between the Black Rock and Korannaberg there are small ill-defined pans, sometimes with a red sandy limestone and mud floors. These hold water for a few days after rain. Similar pans are of frequent

occurrence in the sand-veld further west, but they have hard sandy mud floors only. These pans, though they may contain water for several days or a few weeks after rain, do not seem to be recognised locally as of the same value as the better defined pans, nor are they indicated on the farm diagrams. They are always elongated in the direction of the neighbouring sand dunes, and the floor is usually covered with small bush. During my journey from Upington to Rietfontein, several of these pans between Abiam and Springbok Vley had held water for more than a week.

In the sand-veld just east of long. 22° E. there is a line of pans extending from Kuie Pan in the north to Kakoup in the south, a distance of over 30 miles; though there are wide intervals between the pans, the linear grouping may be due to the geological structure of the area, for the line probably follows the area occupied by the Kheis series. To the east and west of it the Matsap beds, which are on the whole better adapted to resist weathering than the Kheis series, probably come in at no great distance.

Kuie Pan was about four miles long from north to south and some 1,000 yards wide at the time of my visit, when it contained more water than for many years past, though it was possible to cross it dry-footed by a band of schist and limestone outcrops a mile and a half from the north end. This pan is undoubtedly a hollow in the Kheis schists, which crop out all round it so frequently that there is no room left for a depression filled with sand or other superficial rock, marking an old valley. To the east and north the Kheis beds form a few prominent kopjes, and to the west they occur in a long ridge, which rises 200 feet or more from the pan floor. At the south end the outcrops are fewer and smaller than elsewhere, but they were three feet above the water level at that time. The depth of the water seemed to be very slight, less than 12 inches where it was directly observed. After a northerly wind had been blowing for a few hours, the water was driven southwards, exposing a wide stretch of the pan floor at the north end. The quartz-schist on the pan floor and from a well on the east side is of a bright green colour; when the rock can be followed from the level of the floor to a height of one or two feet above it, the green colour is lost. A great part of the floor free from water in April, 1907, was made of the Kheis beds, and sandy limestone covered most of the remaining portion. A sandy calcareous mud is seen where the hard rocks are absent, and it probably forms the greater part of the area covered by water during my visit. The limestone has a greenish colour in many places. It occurs in large flat masses lying on sandy mud, or directly attached to the rock. Three slices were cut from limestones forming outcrops just above the water at the south end of the pan. (1746-8). They show the rock to be a compact limestone, containing grains of quartz, felspar, chlorite, and epidote, and that it is traversed by

veins of more coarsely crystalline calcite. There is no chalcedony or other form of silica, except the quartz of the sand grains.

Lying upon the dyke rock intrusive in the Kheis beds of Kuie Pan (described on p. 84) there are patches of thin limestone. A slice (1753) from this rock contains many pieces of plagioclase and altered felspar, augite, and green decomposition products derived from the dyke rock, together with quartz grains of the usual sort, set in a limestone matrix. Another slice (1753) was taken from the junction of the green schist with the overlying limestone. The two rocks are so firmly joined that it is difficult to break the rock along the junction with a hammer. Seen under the microscope, the limestone is a fine-grained compact rock, but it has some cracks in it partly filled by calcite; the rest of each crack is empty. This matrix contains many angular quartz grains, evidently derived from the schist, white mica flakes, and a few grains of magnetite and felspar. At the upper limit of the schist the quartz grains are slightly displaced, and the interstices are filled with calcite; throughout the 3 mm. of schist seen in the slice, the calcite has made its way downwards between the quartz grains, especially along planes perpendicular to the surface between the schist and limestone, planes which are also those along which most of the mica lies. The water in the pan was very slightly salt at the time of my visit, but I was told that in a few days' time it would be too salt for cattle to drink, owing to the concentration of the salts by evaporation of the water.

To the east and west of Kuie Pan thick sand soon covers both the limestone and the schists. To the north the sand also covers the rocks, but there are outcrops of schists without limestones at Sand Kuie and further north. To the south sand is also abundant, but there are outcrops of limestone towards the Malanie pans. A thin section (1745) from a spot about three miles south of Kuie Pan shows a granular calcite matrix, enclosing rounded and angular grains of quartz, felspar, tourmaline, and magnetite. There are also lumps of more compact limestone enclosed by a coarser matrix, as though the surface limestone had broken up and had become re-cemented by freshly-deposited limestone. From the appearance of many outcrops of surface limestone, it seems that the rock breaks up into various-sized pieces when exposed, and should the outcrops again be covered with sand and the process of deposition be continued, a brecciated rock would result.

The two Malanie pans lie east of the schist outcrop called Malanie Kop, and the same rock appears at the surface again immediately west of the northern pan. The pans are covered with a sandy calcareous mud, with many small fragments of limestone. Limestone of the usual surface type, without chalcedony, crops out round the pans and between them. This limestone forms wide slabs, often broken up into pieces from 2-24 inches across, about 1 inch thick. It does not form a bed

lying at one level, but conforms to the gentle slope of the ground at each spot. The ground slopes towards the pans, and the 700 yards of ground separating the two pans slopes towards the pans from the middle of the rise; it is also made of slabs of limestone with some sand, and the limestone slabs slope with the ground.

Some ten miles of low sand dunes with occasional outcrops of surface limestone in the troughs separate the southern Malanie Pan from Rooi Pan, which is oval in shape, about 800 yards long from north to south by 500 wide. The floor of Rooi Pan is a sandy mud; much of it was covered by water at the time of my visit. Surface limestone crops out at many spots on the west side of the pan, and in fewer places to the north and east. Between Rooi and Gamotep Pans surface limestone frequently crops out amongst the sand. Two thin slices (1743, 1744) from this locality show a brecciated structure, owing to the inclusion of a more compact limestone by a limestone made of larger grains of calcite. Both kinds enclose numerous grains of quartz, quartzite, chert, magnetite, and epidote.

Gamotep Pan lies rather more than a mile south of Rooi Pan. It is about 3,000 yards long by 1,000, or more, wide. The greater part of the floor was covered by water at the time of my visit, but the dry area consisted of a greenish brown sandy calcareous mud. The water was fresh enough to be used for drinking purposes. On the west side of the south end of the pan there is a bank through which a small ravine has been cut, exposing about 15 feet of loose cavernous sandy limestone lying immediately beneath the sand. Neither this rock nor any of the limestones mentioned from the Kuie Pan-Kakoup line were found to contain any shells. A few rounded and sub-angular lumps of vein quartz and quartz-schist lie on the surface of Gamotep Pan.

On the north-west side of Gamotep pan red sand seems to be encroaching upon the floor of the pan; elsewhere the sand near the more or less well-defined edge of the pan is of paler colour than further away from the pan.

Owing to the generally observed association of groups of large pans with the Dwyka series, I specially looked out for boulders that would indicate its proximity or former presence along the line of country where these pans are, but the only rocks foreign to the neighbourhood were small pieces of the banded jaspers from the Griqua Town series and bits of chalcedony, and these were undoubtedly carried there by natives, either in the form of chipped arrow-heads or as pieces of rock for their manufacture. Many well-shaped flakes of small size were found near the Gamotep water-hole (at the rock-hole, not the pan). Though small chips, rarely over an inch in lengh, are numerous in this area, larger implements of the same kinds of rock were not seen though to the east of the Langebergen, along the Orange River above Upington, and at Witsands west of the Langebergen, the large implements are often found.

The Kakoup Pan lies about two miles east of the north end of the Inkruip Range, between high red sand dunes, which run W. 20-30° N. The pan is rather ill-defined, but is about a mile long in the W.N.W. direction, and some 500 yards wide at most. The lowest part of the pan, filled with water at the time of my visit (April 20th, 1907), is made of a sandy calcareous mud. A pit dug in the north-west end of the pan exposes two feet of loose tufaceous limestone lying on a green calcareous sandstone. No shells were seen. The green sandstone is traversed in all directions by branching tubes from a quarter to half an inch wide. The section has a bedded appearance owing to the alternation of softer layers with two harder and apparently more calcareous beds. A thin slice (1742) from one of the hard limestones shows many angular and rounded grains of quartz, chert, quartzite, magnetite, tourmaline, zircon, and a few pieces of felspar, set in a medium-grained matrix of calcite. No trace of subsequent silicification was noticed in the rocks exposed nor in the thin section.

Though the underlying ancient rocks cannot be seen at all of the pans in the Kakoup-Kuie line, there can be little doubt that they belong either to the Kheis or the Matsap series, and that there are no rocks there which can supply the considerable amount of calcite seen in the surface limestone of the area. It is an interesting problem to find the source of the carbonate of lime, but at present the information as to the contour of the surface of solid rocks between the pans and the country east of the Langeberg is too scanty to decide the details of the course of the surface drainage, which, however, is certainly in a general sense westwards towards the sand-veld and southwards towards the Orange River.

Excepting the bedded rock seen at Kakoup, the limestones are devoid of stratification, and they have probably been deposited by evaporating water either within the sandy ground outside the pans or at or near the surface of the muddy pan floors. There is no evidence that any of these pans were formerly more constantly filled with water than is now the case. Had that been so, one would expect to find a molluscan fauna in some of the limestones; but shells were only seen in the limestone of Waterpan in Vryburg, in the Witkop Pan—an expansion of a valley—and in limestones in the Molopo and Kuruman River beds. Where these shells were found, they were so abundant that their presence could not escape notice, and in spite of the fact that the other pan limestones were somewhat cursorily examined, I think it unlikely that they contain shells.

In the south-eastern part of the sand-veld, from Kuie Pan to the Orange River, there are pans without any limestone associated with them. These pans are rather like the pans between sand dunes previously mentioned, but the former have more or less circular outlines, and would appear to be generally better defined than the latter. The floors are made of sandy mud. One

of these pans lies about three miles from Kuie Pan, south of the road to Inchwanin, and there are several of them between Inkruip, Scheurberg and the south end of the Langebergen.

In the country occupied by the Dwyka series, between Upington and Rietfontein, pans are abundant. On Areachap, Rooi Puts, and Steenkamp Puts there are many small pans up to 100 yards in diameter. They are nearly circular shallow depressions in hard pebbly ground. Though there may be an occasional outcrop of grey surface limestone near the pans, this rock is not a prominent feature, as it is in the Kuie group. Outcrops of the Dwyka beds are only found where the rock is a hard limestone, but the variety of pebbles at the surface always indicates the presence of the tillite. In the case of a pan by the road-side on Areachap, a well section within a few yards of the pan proves that the tillite descends many feet below the pan floor.

The north-western part of Gordonia is remarkable for the number and large size of the pans in it. In many cases the Dwyka series crops out very near or in the pans, so that they are probably situated entirely or partly on that group of rocks. In other cases, only sand and other superficial deposits are seen in their proximity.

The Abiam Pan was the first of the large pans seen. The Dwyka tillite occurs to the north, west, and south of it, and there is a considerable amount of surface limestone. The pan floor is a calcareous sandy mud.

Abiquas Puts is of particular interest, because it received water from the Kuruman River in 1894. The old course of the water was down the Hygap, but that bed had been blocked by drift sand, and the water was diverted to Abiquas Puts. The Dwyka series underlies the surface to the north-west of the pan, but sand dunes occupy most of the country round it.

The Narougas Pan is a flat surface of about nine square miles of grey sandy mud, surrounded on the north, south, and east sides by red sand-dunes. On the west side there are outcrops of the Dwyka series and dolerite, but no outcrops were seen on the floor of the pan. It is separated from the Skuynskalk Pan by a belt of red sand-dunes. The Skuynskalk Pan is about five miles long and over three wide; it is elongated in the direction of the trend of the sand-dunes in the neighbourhood, about east and west. When I crossed it, there was water along the southern side, but the depth was not over three inches. The floor of the pan is of sandy mud. In places the surface was sun-cracked, and the top film of mud had a smooth surface, which reflected light well. This film was often divided up into small areas by the cracks, and curved up at the edges, exposing a more sandy substratum. The mud of the floor of this pan is more clayey and less sandy than usual, and evidently shrinks considerably on drying. The pan is surrounded on all sides by red sand, but wells on the north side prove that the rock there

belongs to the Zwart Modder beds, and not to the Dwyka series.

The Kopjes Kraal Pan is about nine miles long in the north-easterly direction, and five wide. It lies partly on the Dwyka series, and partly on the Zwart Modder beds. The floor is a light-coloured sandy mud, and in the northern half this mud is very thin, allowing the joints in the rocks below to make themselves seen on the surface, and in places the rocks are exposed. A remarkable feature is the occurrence of two parallel dolerite dykes, stretching across the northern part of the pan in a west-north-westerly direction. These dykes have not been cut to a level surface with the enclosing rock, and stand up from the floor like walls. The pan is surrounded by sand-dunes on the south, east, and north-east, but there is probably a krantz of the Zwart Modder beds, of which part is exposed at Blaauw Krantz, limiting both Kopjes Kraal Pan and the still larger Haakschein Vley, on the east, but the greater part of the krantz is buried under sand. It is likely that this krantz represents a surface feature of Dwyka times, for a patch of pebbly Dwyka shale (see p. 80) was found three miles north of the Wind Hoek dam below the outcrops marking the extension of the Blaauw Krantz cliff.

On the top of the Blaauw Krantz section there are seen about 50 feet of sandy limestone and sand. The rock lying immediately upon the Zwart Modder beds is a soft sandy limestone, riddled with winding passages filled with sand; this rock is about four feet thick. It is followed by some 30 feet of similar but looser rock, and this in its turn is overlain by five feet of harder limestone which passes under sand. In thin slice (1835) the rock is seen to be a compact limestone, with veins and patches of more coarsely crystalline calcite in it; these two kinds of limestone enclose grains of quartz, felspar, magnetite, garnet, and zircon. At the south end of the krantz the limestone can be seen passing downwards under the sand, and in isolated patches nearly to the level of the pan, but they do not appear on the pan surface.

Haakschein Vley is the largest pan in Gordonia, and probably also the largest in Cape Colony; it is 14 miles long in a north-north-westerly direction, and six miles wide at the broadest part. The western side is on the Dwyka series, seen in occasional outcrops and in a few holes dug in the hard mud ground west of the pan's edge. The southern edge is on shales and sandstones of the Zwart Modder series, and the same rocks are seen occasionally on the eastern side amongst the sand-dunes, which there limit the pan, and again in frequent but small outcrops on the floor of the pan itself. The greater part of the floor of the pan is madeof a pale-coloured sandy mud. Both on Haakschein Vley and Kopjes Kraal Pan there are patches of white salts on the surface, near the edges of the pans; these layers are very thin, and do not completely cover the sandy mud. On the hard ground, partly bare outcrops of the Dwyka series and partly

hard mud, on the west side of Haakschein Vley, there are stream channels which lead storm-water to the pan. They evidently bring considerable quantities of mud into the pan, but in spite of this, the pan does not seem to be silting up. Mr. Rautenbach of Skepkolk, who has probably known Haakschein Vley longer than any other white man, told me that the patches of bare rock on the floor of the pan have increased in size and number during the past 40 years. The only means by which material can be taken out of the pan is the wind. I happened to cross the pan on a rather windy day, and the amount of very fine dust in the air on that occasion was very great. At times one could not see trees or other conspicuous objects 300 yards away, yet the wind was not strong. No vegetation grows on the pan floor, and the red sand from the east and north, if ever it tends to invade the pan, cannot get a permanent resting-place there. The rocks which crop out on the floor are not very resistant to the great diurnal changes of temperature, and do not appear to retain a surface long enough to receive a polish from the action of sand and dust blown over them. This is even true of an outcrop of dolerite seen about two miles north of the Wind Hoek dam; the surface of the dolerite is crumbly, and at least the felspar is considerably decomposed. Probably the salts, which must be present in small quantity throughout the pan floor, aid the processes of weathering. The occasional pebbles of quartz and chalcedony, probably derived from the Dwyka tillite, show distinctly the effects of wind-borne sand, though the "dreikanter," more or less sharp-edged facetted pebbles shaped by that action, were not observed.

Between Kopjes Kraal Pan and the Salt Pan, nine miles to the south-east, there are many long red sand-dunes, trending about W. 15° N. The sandy limestone seen east of Kopjes Kraal Pan soon disappears under the sand, but a precisely similar rock crops out round the Salt Pan and for some three miles north-west of it. Two miles north of the Salt Pan there is another pan, about a mile long and 500 yards wide, with a visible amount of salt mixed with the surface of hard sandy mud. There are no outcrops of hard limestone round this pan, but at the south-west corner there is an exposure of about three feet of laminated sands, white, grey, and yellow, in layers up to two inches thick; the white layers are harder than the others, and contain more lime. The layers slope towards the pan. The exposure is only four or five feet long. No shells or other fossils were seen. A remarkable feature in this pan was the enormous number of dead locusts and beetles on the floor. In places they were so arranged in belts that it was obvious that they had been in the pan when there was some water in it. The Salt Pan is well known in the district for the amount and excellence of the salt on its floor. At the time of my visit there was a solid crust of salt from one to two inches thick lying on black salt sandy mud. Water was met with three inches below the

surface. The salt crust is divided up into polygonal areas, analogous to the areas enclosed by cracks on dry mud flats. The cracks in the salt crust are filled with salt, whiter and containing less impurities than the crust itself. This very white salt forms low ridges, up to half an inch high, over the cracks, and it is evidently deposited by water rising along the cracks and evaporating at the surface. The pan is nearly three miles long, and about a mile wide at the broadest part. The salt crust extends almost to the edge of the pan. There is no apparent explanation of the large amount of salt in this pan, the only one on the west of the Hygap which contains much. It does not seem to receive water from a larger area than, for instance, Haakschein Vley. Another salt pan called Matsiman exists to the east of the Hygap in this region, but I have not seen it.

Analyses were made of the salt from the two pans by Dr. C. F. Juritz, Senior Government Analyst; the figures are:—

| | No. 1. | No. 2. |
|---|---|---|
| Calcium sulphate ... ... ... | Very faint trace. | Very faint trace. |
| Magnesium sulphate ... ... | Trace. | Trace. |
| Sodium sulphate ... ... ... | .48 | .62 |
| Sodium chloride (common salt) ... ... ... ... ... | 98.55 | 98.31 |
| Moisture ... ... ... ... ... ... | .01 | .29 |
| Sand (insoluble matter, estimated by difference ... | .96 | .78 |
| | 100.00 | 100.00 |

No. 1 is the salt from Rautenbach's Pan; No. 2 that from Matsiman Pan. The resemblance between them is very striking, and so is the percentage of sodium chloride. The Matsiman sample was obtained from a native at Wit Krantz, on the Kuruman River, who had recently come from the pan. The other sample was taken from the crust on Rautenbach's Pan. It cannot represent the composition of all the salts held in solution by the water which deposited it, for water was found three inches below the surface, so the most soluble constituents were probably still in the water. The very small amount of calcium sulphate, a substance of wide distribution in pans and in the soil of areas without efficient drainage, is probably to be accounted for by the facts that the deposit at this pan is thick, very likely thicker than the salt crust taken out, and the calcium sulphate is much less soluble than common salt, and would have been deposited earlier, in the black sand or below it.

## *Water Supply.*

The country described in the previous pages is probably on the whole the worst watered area in the Colony, so far as water for domestic purposes and stock is concerned. The actual rain-

fall is not known, except at Upington (8.67 inches a year, an average of 9 years before 1894)[1] on the southern border; since 1894 the rainfall does not seem to have reached 5 inches. The country generally seems to be remarkably well covered with grass and bush, but this abundant vegetation is confined to the sand; on the hard ground near the German border, along the Orange River, and in the small areas found amongst the sand, the vegetation is of the Karroo type, short, sparsely scattered bush with drought-resisting leaves. The explanation of the difference probably is that in the sand-veld there is a thick layer of damp sand, the depth of which changes but slightly from year to year, and which supplies the trees throughout the year with water, possibly the grass also. In the hard veld there is no such damp zone at a moderate depth; the ground seems to be dry generally to a considerable depth, and then there is the layer of ground water which supplies wells when tapped.

From inquiries made on the journey, the usual experience of those who dig for water in the sand-veld is that damp sand is met with at a depth of 8 or 10 feet below the surface; but the water is never in sufficient quantity to collect in a well; after passing through many feet of damp sand, dry sand is again encountered, and usually no further water is found, even though the well be sunk to bed-rock.

The sand of the sand-veld allows rain water to penetrate the ground rapidly, and yet is not coarse enough to let the moderate or small quantity received run through to bed-rock or a less pervious layer; the water is thus held in the sand by capillarity.

The only successful wells met with west of the Langeberg-Korannaberg range were sunk in the river beds or in the hard ground near the German border. It is probable that water in moderate quantities could be obtained anywhere along the Kuruman River below Dikgathlon, at depths of less than 100 feet. The existing wells, except that of Wit Draai (80 feet) are not deep enough. The Witkrantz and Matlapaning wells at the time of my visit gave a few buckets of water a day, not enough for a small team of oxen, and the Lower Dikgathlon well was very weak; if these wells were deepened, they would very probably yield much more water than they now do.

The conditions in the Molopo above its confluence with the Nossob seem to be more favourable than those of the Kuruman bed, for water at a few feet below the surface is got between Kolingkwani and Kuis. Both in the Molopo and Kuruman Rivers the reason why deep wells have not been made probably is that the well sinker would have no security of tenure; otherwise the value of the water for stock and its sale to users of these routes to the German border would certainly have induced people to make satisfactory wells.

Both the Dwyka and the Zwart Modder beds afford water in

---

[1] A. Buchan: A Discussion of the Rainfall of South Africa, etc., 1897.

the country near the German border; the wells are, of course, sunk on the patches of hard ground; those seen by me were less than 100 feet deep. The water from the Zwart Modder beds is generally less brak than that from the Dwyka. There seems to be little difficulty in getting moderate supplies of water in the hard veld; west of the Hygap the country has a very small slope, and in spite of the scanty vegetation, the amount of water which runs off is probably small in proportion to that which evaporates at the surface or sinks underground along joints. It is likely that the conditions are more favourable along the German border than east of the Hygap, where the patches of hard ground are few and surrounded by thick sand, for the latter to a great extent prevents the rain-water from reaching the solid rocks from which it might be obtained by wells.

The sand-veld holds water in a way that is favourable to vegetation, but not to the supply of wells, and in the case of the hard-veld the conditions are reversed.

# GEOLOGICAL SURVEY OF PORTIONS OF MAFEKING AND VRYBURG.

---

By ALEX. L. DU TOIT.

---

# GEOLOGICAL SURVEY OF PORTIONS OF MAFEKING AND VRYBURG.

By Alex. L. du Toit.

## I. Introduction.

The area examined is a continuation in a westerly direction of that mapped in 1905, and includes a triangular portion of country between Pitsani, Genesa, and the Molopo, extending westwards to a little beyond Morokwen.

As the work progressed, it became evident, owing to the great development of the superficial deposits, that the production of a map showing the solid geology would be almost an impossibility. The map (sheet 52) which has been issued shows therefore as far as possible the actual exposures of the formations only, but the approximate limits of some of the areas occupied by certain of the formations are indicated by means of broken lines.

Opportunity was taken of the improved transport facilities in revising wherever the routes permitted the boundary lines of the previous survey. This was especially the case along the belts occupied by the Kraaipan formation, where the mapping was done on a somewhat larger scale and where the work was aided by the presence of new prospecting shafts and trenches.

*Physical features.*—The whole of this area consists of rather monotonous, slightly undulating country, with an almost imperceptible fall towards the north. It is traversed by a number of shallow depressions or laagtes—they can hardly be termed river-valleys—which extend towards the north or north-west and unite with the Molopo. Between each pair of laagtes the ground rises from 100 to 200 feet and forms a low bush-clad rise or "*bult*."

From Genesa there is a gentle fall towards Morokwen, after which the country rises and culminates in a chain of low hills, the highest of which is just about 4,000 feet above sea-level. From this ridge to the Molopo there is a fall again amounting to about 500 feet. Over this wide area the soil is always a light yellowish or pinkish-red sand, supporting a long coarse grass and dotted over with shrubs and thorn trees. Towards the Molopo the vegetation becomes thicker, and from Mabul onwards there is a belt of dense bush, from eight to 15 miles in width, which is continued on the north bank far into the

Bechuanaland Protectorate. This forest-belt should prove very valuable, for there are large numbers of Camelthorn trees (*Acacia giraffae*), besides other acacias, which afford good timber. Beyond Morokwen there is a large tract occupied by the Hakdoorn (*Acacia detinens*).

The rainfall of this area is apparently somewhere about 20 inches annually but owing to the sandy nature of the soil it is only for a short time in the wet summer season that any water flows in the rivers.

*Geology.*—Granite and gneiss is the underlying formation over the greater part of the area; beyond Morokwen the rocks of the Transvaal system appear. Superficial deposits conceal large tracts.

The formations can be arranged as follows:—

| | | |
|---|---|---|
| | Superficial Deposits | Sand, limestone, surface-quartzite, red marl, etc. |
| Transvaal System | Griqua Town Series (Lower) | Banded jaspers, ironstones, and cherts. |
| | Campbell Rand Series ... | Limestones, dolomites, cherts and shales. |
| | Black Reef Series ... | Quartzite, arkose, and conglomerate. |
| | Kraaipan Formation | Banded magnetic rocks, cherts, jaspers, and slates with interbedded diabase, amygdaloid, rhyolite, and hornblende-chlorite- and calcareous schists. |
| | Granite and gneiss. | |
| | Schists in the granite and gneiss. | |

(The wavy line denotes an unconformity.)

There are a few basic dykes penetrating these formations. A dyke on Saints' Rest, near Genesa, and another in the dolomite north of Morokwen are ophitic dolerites of the Karroo type. Four dykes crossing the Mosita valley on Gemsbok Pan, Groot Gewagd, and Klip Pan are diabases of pre-Karroo age.

## II. The Schists in the Granite.

Along the Setlagoli River, on Steil Hoogte and Krom Draai, the granite has inclusions of hornblende schists, like those previously recorded from Mafeking.[1]

Some of the larger masses are almost entirely of hornblende and are well foliated. The inclusions are seamed by threads and veins of granite, aplite, and pegmatite, and portions have frequently been fractured across the foliation planes and faulted. In a few places beautifully-banded composite gneisses have been produced, with foliation planes striking a little west of north.

[1] Ann. Rept. Geol. Commn. for 1905, p. 210.

On the Madeakham Native Reserve, a well has been sunk in biotite-gneiss, containing inclusions of amphibolite traversed by veins of granite, aplite, and pegmatite. Banded gneisses were also struck in a well on the farm Venter's Rust far down the Genesa laagte.

Petrologically these "schists" are characterised by an abundance of sphene, usually accompanied by epidote. Microcline, so charactertistic of the granite, is absent, and the felspars are orthoclase and plagioclase.

Whether these rocks were originally of sedimentary or igneous origin is not clear, for the occurrences in Mafeking are not on a large enough scale to decide this point. As similar rocks are found in the Prieska granite[1] it is possible that further evidence will be obtained in the area south of the Orange River.

The banded composite gneisses indicate in all likelihood that these rocks already possessed a foliated structure at the time of their invasion by the granite.

Partly digested inclusions, the true nature of which can still be recognised, are not uncommon. A section (1712) of one of these from a patch in the granite one-and-a-half miles east of Setlagoli shows the following minerals under the microscope:—Quartz, orthoclase and plagioclase, chlorite (representing biotite and hornblende), epidote, and abundant sphene. The structure varies from schistose to granulitic.

It seems most likely that some of the banded granulitic gneisses in Mafeking represent the ultimate stage of metamorphism and absorption of these schists by the granite, for usually they are rich in sphene and epidote, while there is a deficiency of microcline felspar.

## III. The Granite and Gneiss.

The granite is rarely exposed in the area between Mosita and Morokwen, but it has been struck in a number of wells and boreholes, and its extent must be considerable. Small exposures are found at Genesa and in a few of the shallow valleys, which are so characteristic of this part of Bechuanaland, while the rock is also exposed in a couple of pans at Morokwen. There are wells in granite or gneiss at Tlakgaming and Khudungkwani, while in the First Railway Grant to the north, granite has been struck in all boreholes. Along the Genesa and Tlakgaming laagtes there are a number of wells, *e.g.*, Wegdraai, Chwabe, Reitzdale, Donegal, Inverness, as far north as Venter's Rust. Beyond the last named, the Black Reef and Campbell Rand formations appear, and the approximate limit of the granite can be fairly well defined.

Between Khudungkwani and Mosita there are several wells in granite, *e.g.*, Kalk laagte, Bont Bok, Wilde Als Put, and

[1] See p. 163.

Doorn Bult, but the area to the north, including the Western Railway Grant (in Mafeking) is almost without wells, or else the superficial deposits have not been penetrated in well sinking.

The granite varies considerably in character, but is generally a medium-grained pale-pinkish variety with either muscovite or biotite mica; pegmatite veins are common. The strike of the foliation planes varies generally between north and north 30° east. Sometimes the rock is massive, at other times gneissic, while not unfrequently there are alternations of foliated and unfoliated granite.

Porphyritic varieties, with large crystals of pink felspar, occur on Woodrust, just north of Genesa, and again at Morokwen, where there are extensive outcrops at the western end of the pan. These varieties recall the granites of the Motiton Reserve.[1]

## IV. The Kraaipan Formation.

Upon following the Mosita belt northwards past Logaging, an excellent section was found along the Setlagoli River, where the various members of this formation have been exposed on the banks of that stream. Over wide areas the exposures of this belt usually consist of the more or less isolated outcrops of the hard magnetic and cherty rocks, separated by stretches of red sand. Here, however, the softer strata, which alternate with the harder beds, are well exposed and consist chiefly of volcanic rocks more or less sheared, together with quartzites and calcareous schists. The section is so important that it will have to be described in detail (fig. 1); by its means many difficulties in the interpretation of the succession in the case of other exposures of this formation have been removed.

The lowest beds are seen along the river about half-a-mile below the homestead on Logaging and again just behind the house. The granite on which these beds must rest is not exposed, the rocks towards the west being hidden by sand and tufa. The rocks forming zone 1 are green diabases and amygdaloids and sometimes breccias, with thin layers of magnetic quartzite interbedded between some of the flows. One of these layers can be followed for about half-a-mile, and varies in thickness from a few inches up to two feet, as a rule, but to the south it becomes much thicker. Its outcrop is shifted a number of times by means of small transverse faults.

Near the junction with the first important ironstone band, zone 2, the lavas become more cleaved and jointed and are sometimes much sheared; the rock at the actual junction is rather crushed and considerably decomposed.

Towards the southern boundary of Logaging there is a narrow band of rhyolite, which swells out as it is followed southwards

[1] Ann. Report for 1906, p. 11.

until it attains a width of a couple of hundred feet. Sometimes it exhibits beautiful flow structure; occasionally it contains spherulites and lithophyses; often it is very fine-grained and has a cherty appearance. It is accompanied by breccias.

The rhyolite appears to be a lenticular intercalation in the diabase, a little below the base of zone 2, and is parallelled by the acid volcanics near Mosita.

The rock composing zone 2 is a finely-banded magnetite jasper rock. About half a mile above the homestead on Logaging the river has cut a narrow notch through this zone, the strata at this point being vertical, and the thickness does not exceed about 100 feet. Further down the river the breadth of the outcrop increases, and the hill on which the beacon called Kging stands owes its width to the repeated folding of these intensely hard ferruginous rocks; this zone is succeeded by a great thickness of green diabases and amygdaloids, accompanied by "pillowy lavas" and breccias (zone 3), and these in turn by a prominent belt of banded red jaspers and cherts, cherts without banding, and banded magnetite-jasper rocks. The jaspers are as a rule confined to the western side of the zone, but there is great variation, for some of the pale cherts pass into brilliant red jaspers along the strike. All these hard rocks are more or less faulted or brecciated, and the space between the blocks is filled with greyish chert.

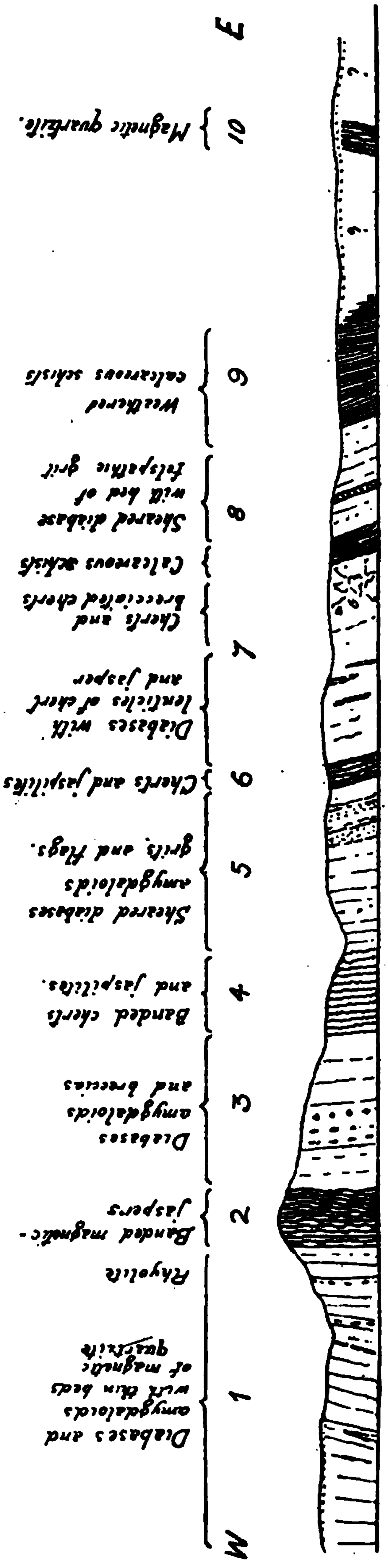


FIG. 1.—Generalized section across the Kraaipan formation from the exposures along the Setlagoli River between Logaging and King's Mill. Distance across the strike of beds about two miles.

Following zone 4, and best seen on Martin's Bush, is another broad belt of volcanic rocks, green in colour and often highly sheared. Peculiar lenticular inclusions of yellow and brown weathering crystalline limestone are probably metamorphosed vein material. These are followed by dark green gritty rocks, some of which appear to be tuffs, and by soft greenish sandstones and flags, which weather with a purplish tint. They are succeeded by cherts and jaspers, very like those of zone 4, but undoubtedly on a higher horizon (zone 6).

The same zone appears further up across a bend in the river, on Kingsmill, at the junction with the Mosita River. It is followed by diabase and amygdaloid, containing narrow bands and lenticles of chert and brilliant red jasper. Next come colourless to greenish grey banded cherts and masses of cherty brecciated rock with fragments of vein-quartz, probably much shattered quartz veins, followed by greyish cherts. Succeeding them is a considerable thickness of rocks, which are very probably calcareous schists, for they are deeply weathered and produce much tufaceous limestone, and leave a network containing green and yellow brown ochreous earthy material.

On the opposite bank of the river, and apparently a little higher up in the succession, we find sheared greenish diabases, between which is intercalated a bed of felspathic grit, about 15 feet in thickness. This grit, or arkose as it is almost entitled to be called, yields most conclusive evidence to the conditions under which rocks of the Kraaipan formation have been deposited. The thin section (1689) shows under the microscope little fragments of quartz, sometimes polarising as a mosaic, and usually showing dusty inclusions; orthoclase, full of tiny flakes of some micaceous mineral, is abundant; plagioclase is present in small fragments. The rock contains fragments of chert, jasper, grit, cherty limestone, rhyolite, and possibly diabase.

It is probable that while this layer was being formed, the lower beds of the Kraaipan formation were undergoing denudation; the abundance of quartz and felspar obviously suggests their derivation from the granite.

The beds immediately succeeding the diabase overlying this grit are not seen, but further up the river are thin-bedded brownish weathering schists, probably of a calcareous nature. After this there is a gap for several hundred yards, and then a band of magnetic quartzites dipping to the west at a high angle crosses the bed of the river.

No further outcrops are seen along the Setlagoli for some distance, and then on Steil Hoogte muscovite-granite makes its appearance. The width of the belt occupied by the Kraaipan formation, where it is cut through by the Setlagoli River, cannot be less than two miles, which will give at least 10,000 feet for the thickness of the series, of which more than one-half is of volcanic origin. As there is not sufficient space between the highest beds and the granite on Steil Hoogte for the different

zones to occur in reverse order, it is probable that the eastern boundary of the belt will be a fault.

On following the belt southwards up the Mosita valley, good sections are found on the farm Blikplaats, where the river has cut its channel along the belt. The diabases of zone 1 are exposed around the homestead, and again in the bed of the river; here also they include thin layers of magnetic quartzite. The magnetite-jasper rock of zone 2 is a little more quartzose than on Logaging, and in a similar manner crosses the valley like a wall. The trigonometrical station is situated on a hill formed by the repeated folding of this stratum.

The third zone can be traced for a considerable distance northwards down the river, but is buried beneath sand to the south, on Moshesh. Zone 4 (cherts and jaspers) is present on the right bank of the river, and extends into Moshesh, where it is much folded. Its character has been previously described.[1] The higher zones are either absent or concealed by red sand.

On Moshesh the granite was proved west of the belt in a well in the bed of the river, but the lowest zone of diabase is not exposed between the river and the ironstones of zone 2.

On the farms Hope and Faith certain volcanic rocks, which were stated in the Report for 1905 to probably belong to the Ventersdorp series, were found to be actually the lowest portion of zone 1. The structure is apparently a synclinal one, parallel in direction to the main belt lying to the east, and the rocks crop out more or less on the left-hand side of the valley, the boundaries being shifted several times by cross-faults.

At the base comes about 150 feet of rhyolite, very hard and with scarcely any visible bedding planes; this is followed by several hundred feet of greenish blue diabase, with amygdaloid structure only feebly developed. The junction between the coarse-grained granite and the rhyolite can be traced for several miles along the western side of the syncline, and the two rocks appear to be almost welded together. It seems that the rhyolite has been poured over a somewhat jagged though not extremely uneven surface of hard granite. Beds of magnetic quartzite appear on different horizons, both in the rhyolite and diabase; they are mostly very thin and rather irregular, and cannot as a rule be followed for any considerable distance.

The lowest one of these beds is found to become more persistent to the south, and on the Mosita Native Reserve it swells out and forms a narrow belt, flanked on either side by granite. It consists of magnetic quartzites and cherts, together with a small amount of diabase, and appears to be a synclinal infold in the granite. The contact with the latter is seen on the south-west side, and it is noteworthy that although there are some white quartz veins in the granite, these are absent in the Kraai-

[1] Ann. Rept. for 1905, p. 225.

pan series, while in one instance the basal layer of magnetic quartzite abuts against a quartz reef. At no point is there any indication that the granite is intrusive.

The exposures of the main belt on the eastern side of Faith and the Mosita Reserve consist of detached ridges of magnetic quartzites, jaspers, and cherts; probably the intervening sand-covered areas between the parallel ridges indicate the existence below ground of the various volcanic zones,[1] but it is not until the northern boundary of the farm Blaauw Krans is reached that the base of the formation is exposed.

The granite is highly sheared here, and is followed by schistose rocks containing blebs of quartz, proving under the microscope to be rhyolites crushed and silicified. These volcanics are succeeded by hard greenish diabasic rocks, and these in turn by a thick bed of magnetic quartzite (zone 2). The volcanics are apparently not more than 300 feet thick here.

A couple of miles further to the south these volcanics make their last appearance, and this zone either dies out in that direction or else is cut out by a strike fault, for the volcanic rocks are absent at Gemsbok Pan.[2]

The western belt dies out just beyond the trigonometrical station Kging on the farm Harriet's Berg, but about six miles further north, on the Molopo, at Kwedi, that river has cut its channel for half a mile through a series of magnetic quartzites and cherts with some light coloured schistose rocks. The beds are somewhat contorted, the general dip being to the east at a high angle.

The Logaging section explains the succession at Pitsani, and renders it clear that the volcanics at the latter locality, believed to belong to the Ventersdorp series, are really a portion of the Kraaipan formation. The diabases, "pillowy lavas," and breccias at the Stad are the basal beds of the formation, as they rest on gneissic granite, and they can be matched with similar volcanics at Logaging. About 1,000 yards west of the Stad are alternations of diabases with magnetic quartzite, ferruginous limestone, magnetic and cherty limestone, cherts, etc., dipping vertically. The diabases are usually more or less sheared, and are sometimes quite schistose.

The ridge through which the river has cut its gorge is formed of massive magnetic quartzites, which probably correspond to one or other of zones 2 and 4, or else to both of them.

Below the poort are again alternations of diabase and magnetic quartzite and chert, and still further west a great development of greenish grits, slates, sheared diabases, and hornblendic schists, with occasional bands of impure chloritic limestone, traversed by quartz veins.

---

[1] Since this belt was examined a number of prospecting pits have proved the existence of sheared rhyolite, phyllite, and magnetic quartzite beneath these sand-covered areas.

[2] Ann. Rept. Geol. Commn. for 1905, p. 224.

The rocks are only seen along the bank of the river for about a mile; further on, the strata are hidden by tufa and gravels, and the only outcrops noticed were those of a few quartz reefs.

Both at Logaging and at Pitsani the succession reckoned from the granite is similar, and in each case the general dip of the strata is towards the east at high angles. It is therefore very probable that the entire succession at Pitsani is an inverted one. The volcanics noticed along the Molopo above Pitsani, and again on the Piring Spruit, will in consequence of these investigations now have to be included in the Kraaipan formation.

At Kraaipan, Wodehouse Kraal, and Madibi, prospecting shafts put down recently have in certain cases shown that no small proportion of the formation must consist of volcanic material. Usually these rocks are diabases, sometimes they are more basic rocks, while some are apparently tuffs. Owing to the great amount of dynamic metamorphism to which the beds have been subjected in these localities, the volcanics have been sheared and recrystallised, so that they are now represented by hornblende schist, chlorite-biotite schist, chlorite-schist, etc.

West of Mosita a small outlier of magnetic rocks was found on Beaulieu, one of the recently-surveyed farms of the First Railway Grant north of Genesa. The patch is only a few hundred yards long, and consists of contorted magnetite-quartz and magnetite-actinolite rocks, with variable dips and with a general north-north-easterly strike. The formation round about is hidden by sand and ironstone gravel, but gneissic granite was proved in boreholes not far distant from this outcrop. This outlier is of great interest, because it shows the former widespread distribution of the rocks of the Kraaipan formation; it also forms a link between the exposures at Gemsbok Pan and Zoete Inval, and those recorded by Mr. Rogers from Kameel Rand[1] not far from Motiton.

### *Petrological Description.*

*A. Rhyolites.* These are cream-coloured, fine-grained rocks, without any prominent ferro-magnesian constituents. The quartz crystals are seldom much corroded, and they almost always show marked undulating extinction, indicating the great strains which the rocks have undergone.

One section (1418) of a rhyolite collected not far from the junction with the granite on Faith (Mosita) shows abundant crystals of quartz and a large crystal of micropegmatite. The groundmass is full of small whisps of white mica, and a small amount of biotite which is mostly altered to chlorite.

Another specimen (1692) from the same farm contains large

[1] Ann. Rept. for 1906, p. 12.

Carlsbad twins of orthoclase, generally more corroded than the crystals of quartz. The groundmass consists of interlocking areas of quartz and felspar, tiny ragged flakes of biotite altering to chlorite, and numerous little rhombohedra originally of iron carbonates, but which are generally altered to iron oxide.

In slide 1686 from Logaging the quartz crystals show a well-marked zoning, and are sometimes cracked across and faulted.

*B. Diabases, etc.* These rocks are dark green in colour, fine grained, and usually more or less sheared. Amygdaloidal varieties are not very abundant, and when present, the vesicles are seldom large. In thin section under the microscope it is difficult to make out the original nature of the rocks, even in the case of the unsheared varieties. Usually the felspar is still recognisable, as in section 1681, from zone 1 at Logaging; in this slide it occurs as narrow laths and elongated crystals. The original ferro-magnesian mineral has invariably been altered; in the section just mentioned, it is represented by large chloritic pseudomorphs. In most instances augite appears to have been present originally, but is now represented by pale greenish yellow hornblende (uralite), accompanied by a little calcite, epidote, and chlorite.

This is well seen in section 1682, from the same zone at Logaging. The rock shows a good ophitic structure, but the pyroxene is replaced by uralite, and the felspar is quite cloudy and altered. Ilmenite is still present.

In 1691, from zone 1 on Faith, the change has proceeded a little further; the augite is replaced by uralite, and the felspar has given rise to an aggregate of epidote, zoisite, uralite, quartz, and also a little clear secondary felspar.

A more advanced stage of metamorphism is seen in a diabase (1673) from near the base of the formation at Kraaipan station. The large areas of uralite are set in a groundmass of clear felspar, crowded with little inclusions of epidote, zoisite, uralite, etc. The ilmenite is altered to leucoxene and sphene, while the uralite shows a partial conversion into chlorite. The rock is traversed by planes of shear, and there is a tendency to orientation among the uralites and to the arrangement of the felspar in bands. The areas of sphene are drawn out and elongated. Section 1674 of a schistose rock taken from a well at the store at Kraaipan shows elongated and well-formed prisms of indefinitely terminated blue-green hornblende, set in a colourless water-clear aggregate of quartz, plagioclase, and possibly also albite, in which are embedded needles of actinolite and granules of epidote and iron ores.

The rock has been completely recrystallised, and can be called a *hornblende-schist.*

Heavy serpentine rocks were obtained from a prospecting shaft two miles east of Kraaipan, but there is nothing to indicate whether they represent lavas or are intrusions.

The chlorite-schists are probably more closely related to the phyllites than to the diabases, and may possibly represent metamorphosed sediments or fine-grained tuffs. A specimen (1670) from the main shaft at Madibi is a well-foliated rock, showing small interlocking areas of quartz, having inclusions of rutile and sometimes of iron ore. Chlorite is abundant in small, almost idiomorphic, plates. Rhombohedra of calcite or dolomite penetrate the quartz, and are aggregated round the iron ores and sphene, or else are arranged in layers. Magnetite and sphene are abundant, the latter being more or less altered to leucoxene.

*C. Banded Ironstones and Jaspilites.* The thin layers of magnetite-quartz rock which occur intercalated between the lavas in zone 1 are indistinguishable from the thicker beds in hand specimen, but under the microscope are found to retain traces of their original structure.

A thin band from Logaging shows (1683) under the microscope a groundmass of quartz, in which are more or less lenticular or irregular areas of iron ores. The quartz areas are remarkably uniform in size, and are polygonal in outline. In the interior of almost each area is a more or less well-defined circular or oval portion, which is crowded with excessively minute particles, probably iron ores; the boundaries of many of the quartz areas are marked out by films of haematite. Probably the dusty portions of the quartz areas represent original grains of quartz now in process of recrystallisation, with the elimination of the ferruginous material. There are also slightly-brownish patches, which under a very high power appear to be grains of felspar in process of silicification. The twinning is nearly obliterated, but the cleavage planes are marked out by rows of inclusions, little colourless rods chiefly, also flakes of haematite. Many of the quartz areas are traversed by parallel rows of these inclusions, the sole indication of the secondary origin of the quartz. The orientation of the inclusions is different in the various grains, and is therefore not due to schistosity.

The rock appears to have been originally a felspathic quartzite, with a certain amount of ferruginous material. In the process of silicification the iron has been concentrated along certain lines, which correspond more or less closely to the bedding planes of the deposit.

The junction of these thin layers of magnetic quartzites with the volcanic rocks is always sharp, and usually it is difficult to obtain a hand specimen exhibiting the junction intact; there appears to be no gradation from the diabase into the magnetite-quartz rock.

At only one place were there no signs of any discontinuity, namely, on Faith, where a thin bed of green ferruginous rock a few inches thick appeared to have the same origin as the diabase in which it occurred. A thin section (1693) shows a rock with rather irregular bedding, composed of quartz, actinolite, and

iron ores. The quartz forms a very fine-textured mosaic, crowded with needles of actinolite. Round the crystals of magnetite and haematite the needles of actinolite are generally collected, and there results a banded rock with streaks of quartz, quartz with actinolite needles, actinolite, and iron ores. This rock has therefore a great resemblance to the magnetite-actinolite-quartz rocks described from near Maribogo.[1]

A specimen (1676) from a shaft two miles east of Kraaipan is a greenish actinolite rock, with layers of brownish quartz, and in section shows crystals of clear actinolite, possessing a pleochroism from pale green to colourless, two finely-developed cleavages, and occasionally good twinning.

Magnetite is present in quantity, and is arranged in bands alternating with the actinolite. Apatite is abundant as inclusions in the amphibole along certain bands. This rock, the bulk of which consists of amphibole, grades into one rich in magnetite (1677), the iron ore occurring in well-formed octahedra. A portion of the iron of the actinolite has separated out in the form of limonite along the cleavage cracks, and the mineral is non-pleochroic.

The mineral here termed actinolite appears to approach very closely to the so-called grünerite of the Lake Superior region, but it differs in several respects from the type mineral grünerite, The density, as determined by a heavy solution, is somewhere about 3.2, and it is probably intermediate in composition between actinolite and grünerite and may possibly be the variety known as cummingtonite, in which some of the iron is replaced by magnesium. The mineral in 1676 is certainly nearer actinolite than grünerite, and possesses a weak pleochroism, a high double refraction, and a well-developed twinning parallel to the orthopinacoid. It is interesting to note that while the amphibole of the Kraaipan ironstones is the ferriferous and magnesian variety actinolite, that of the Griqua Town ironstones is the soda-rich ferriferous variety crocidolite, and each of these is a non-aluminous amphibole.

One of the best illustrations of the development of the actinolite is provided by a specimen from the farm Beaulieu, north-east of Genesa. The section (1706) shows a quartz mosaic, in which the individuals are remarkably uniform in size, and somewhat elongated in the direction of foliation. Between the quartz individuals or penetrating them are small elongated areas of pale actinolite, usually irregular in outline, and never definitely terminated. In certain bands the actinolites become larger, showing cleavage and twinning, and including numerous little areas of quartz and granules of iron ores. The more ferruginous layers show large octahedra of magnetite embedded in quartz

[1] Ann. Report for 1905, p. 233.

and actinolite accompanied by haematite, probably of secondary origin. Apatite is abundant in the form of minute prisms.

The banded ferruginous cherts are very much like those of the Griqua Town series, showing layers of granular quartz and of magnetite and haematite, the rocks being completely recrystallised. The layers are often broken by small faults, which are occupied by narrow veins of quartz.

The banded jaspilites from Moshesh are interesting rocks, for they show two and sometimes three different series of quartz veins, the earlier of which have experienced earth movement, by which the quartz has been granulitized. The iron is in an extremely finely-divided condition, and is probably mostly in the form of minute flakes of haematite; often they are so crowded together that the base of the rock cannot be resolved. The haematite may be accompanied by magnetite. A section (1695) from Moshesh shows numerous minute rhomboidal areas, which are more abundant along certain layers in the rock. Usually these rhombohedral spaces are occupied by quartz in minute areas, grains of iron ore, some dusty matter, and tiny granules of a pale yellowish indeterminate mineral, and they are set in a groundmass of chert and iron ores. Sometimes the rhombohedra show an interior of chert and dusty material, a narrow zone of almost opaque iron ore, and finally an exterior shell of clear chert. It can hardly be doubted that these areas represent rhombohedra of carbonates of iron and lime, and that the rock owes its present character to the silicification of a chert containing rhombohedra of iron-bearing carbonates, which were arranged along the bedding planes. Such rocks are represented by certain cherts in the Campbell Rand and Black Reef series, and seem to have arisen from the alteration of extremely fine-grained siliceous sediments, containing small amounts of carbonates of lime and iron.

It is interesting to note that some of the banded ironstones of the Griqua Town series show similar rhomboidal areas of chert and iron ore, usually bordered by limonite and set in a groundmass of colourless chert.

### *The Origin of the Banded Ironstones and Jaspilites.*

The evidence collected so far points to these ferruginous and cherty rocks as deposits of sedimentary origin, interstratified with the volcanics. With the one or two exceptions that have been referred to already, these beds are sharply defined from the volcanics with which they are intercalated; the exceptions described very probably indicate the mingling of volcanic detritus with the sediment then being deposited.

The remarkable regularity of most of the ferruginous and cherty zones, recognisable often over wide areas, indicates a state of even deposition that did not obtain in the case of the

volcanics. This regularity is exhibited to a remarkable degree both in hand specimens and in thin sections under the microscope, and there cannot be the slightest hesitation in concluding that this banding, as indicated by the layers of different mineral composition, represents an original structure due to variation in the nature and composition of the sediment deposited, and therefore that they are planes of bedding.

The shearing which these rocks have subsequently undergone has produced intense puckering and contortion of the laminae, more especially in the case of the magnetite-quartz rocks, but the jaspilites seem to have been less plastic and more brittle, and the effect of earth-movements has been to brecciate these rocks to a wonderful degree, without however obliterating their original structures. The shearing has sometimes been so intense that strain-slip cleavage (ausweichungs-clivage) has been produced in certain of the layers, but in no case is there any uncertainty regarding the original lamination. (See also Ann. Rept. for 1905, p. 229.)

The origin of the cherty rocks and jaspilites is a problem which seems to offer less difficulties in the way of a satisfactory solution than that of the more magnetic varieties.

From what has been said on pp. 135-7, it seems most probable that these rocks were derived from fine-grained sediments, highly siliceous in character, but carrying small amounts of carbonates, principally those of calcium and iron, probably that of magnesium also. In one of the jaspilite sections (1694) there are small oval bodies, composed chiefly of chert and haematite, that have a considerable resemblance to the altered "greenalite" granules of some of the cherts of the Mesabi area, Lake Superior.[1] They are, however, not abundant in the slide, and may very probably be of secondary origin. In the metamorphism of the sediments the calcareous matter has separated out in the form of minute rhombohedra, and the abundance of rhomboidal areas along certain lines of bedding indicates their formation along bands richer in carbonate than the rest of the rock. A further change has resulted in the oxidation and removal of the calcareous material, and the rhombohedral spaces are thus occupied by chert, haematite, and limonite. The minute specks of haematite diffused through the cherty groundmass may in part have been derived from the iron leached out from these minute rhombohedral spaces, but some of it has apparently been introduced subsequently. It has already been remarked that the jaspilities are much fractured, and that one set of these fractures is considerably earlier than the others. The process involved in the leaching out of the iron and its subsequent dissemination through the groundmass is evidently intimately connected with the solution of the silica and the infilling of these fractures with quartz.

[1] United States Geological Survey. Monograph 43. 1903.

Thus certain small areas bounded by minute veins of quartz are frequently almost opaque from the abundance of granules and flakes of haematite, while in those adjoining the pigmentation is much less intense; at the same time, the bedding is still recognisable.

The mineral transference appears therefore to have been most active at the period of formation of the first series of veins. On a large scale, this variation is found in the field, for beds of brilliant red jasper behave most irregularly along the strike, and may be replaced within a short distance by nearly colourless banded chert. This variation does not imply any marked change in chemical composition of the rock, for the actual amount of haematite in the bright red jaspers is as a rule very small indeed.

The problem of the origin of the magnetite-quartz and magnetite-actinolite rocks is a much more obscure and difficult one.

Much as the Kraaipan ironstones resemble the lithologically similar iron ores of Lake Superior or of Scandinavia, they nevertheless do not show sufficient evidence of having been derived in exactly the same way as the ironstones in either one or other of these two regions. In the case of the American ores, it has been shown[1] that the magnetite and haematite have been formed by water circulating through ferruginous cherts and carbonate rocks, with consequent recrystallisation and metamorphism of the material so altered. The ores consist of more or less lenticular, and sometimes irregular bodies included in masses of chert and limestone, and each lenticle of iron ore if followed downwards will probably ultimately be replaced by one or other of these two rocks. The change has evidently taken place in the surface zone of alteration.

The Scandinavian ores[2] show the same variation in iron-content, and appear to be all connected more or less closely with masses of igneous rock of various types, the alteration having taken place in the zone of anamorphism.

In the Kraaipan ironstones the original bedding is everywhere recognisable, and so far as can be judged, there seems to be no reason to doubt that each zone will maintain its ferruginous character if followed downwards below the surface. This is not capable of direct proof, but the following can be put forward in support of such an assumption:—Pebbles of banded ironstone and jaspilite are found in the conglomerate at the base of the Pniel series east of Mosita, showing that the rocks of the Kraaipan series exposed at the time of the formation of the conglomerate possessed the same lithological characters as in the outcrops that are to-day visible. Bearing in mind the

[1] C. K. Leith: Bi-monthly Bulletin of the American Institute of Mining Engineers, No. 3, 1905.

[2] H. Sjögren: Bi-monthly Bulletin of the American Institute of Mining Engineers, No. 18, 1907.

great amount of denudation that the outcrops of the Kraaipan formation have undergone since the removal of the overlying Pniel conglomerate we have a strong argument against believing the metamorphism of the ironstones to be merely a superficial phenomenon. The changes which the rocks experienced must therefore in all probability have affected each layer throughout its original extent in a regular though not necessarily uniform manner, and these changes had been completed at a period anterior to the formation of the rocks of the Ventersdorp system.

The only alteration comparable with that which produced the Lake Superior ores is the alteration of some of the magnetite to haematite, a change which has taken place in the surface zone. At Madibi a banded ironstone from the 250 foot level is a black and white magnetite-quartz rock devoid of haematite, while at the outcrop all the ironstones have red and brown tints. From this it must be concluded that the haematite is an alteration product of the magnetic iron, a conclusion strengthened by the fact that wherever the ironstones have been much brecciated the proportion of haematite is high. There has evidently been a circulation of water along the lines of fracture, and some of the magnetite has been oxidised to haematite. The quartz may even in certain cases have been replaced by haematite with the production of almost pure iron ores.[1]

This concentration of the iron is not so common, however, in the Kraaipan formation as in the Griqua Town series, where the process has taken place on a huge scale with the production of the Blink Klip (haematitic) breccias.[2]

Again, it cannot be assumed that the Kraaipan ironstones have been derived from impure ferruginous limestones and dolomites by a process of solution and recrystallisation. At Pitsani and again at Kraaipan there are intercalated between the magnetic quartzites layers of ferruginous limestone, into which the magnetic rocks grade almost imperceptibly. As the formation maintains a lithological uniformity over great distances round about, it seems hardly possible that such small layers of carbonate rock should have completely escaped alteration while the rest of the formation became wholly recrystallized and converted through metamorphism into schistose rocks devoid of carbonates but containing magnetite. Again, in the sheared diabases are veins and lenticles of ferruginous and chloritic limestone, while between banded ironstones at Madibi occur beds of calcareous schists with small crystals of magnetite.

It seems curious, too, that supposing the recrystallization to have been caused by the extensive circulation of waters underground, no alteration should have been produced either in these carbonate-bearing rocks or in the volcanics with which the ironstones are interbedded. The diabases show alterations of

[1] Ann. Rept. for 1905, p. 233.
[2] Ann. Rept. for 1906, p. 35-39. Trans. Geol. Soc., S.A., Vol. IX., p. 6, 1906.

the mineral constituents, it is true, but these are more of the nature of paramorphic changes, and the lavas never exhibit the extensive silicification which has often affected the volcanics of the much younger Ventersdorp system. Neither in the diabases nor in the granite have there been found any veins filled with quartz and iron ores such as would be expected had the metamorphism been accompanied by the extensive transference of mineral matter through the agency of solutions.

Taking all this evidence into consideration, it appears that the mineralogical changes that took place in the formation of the magnetic rocks have been more of the nature of a rearrangement of the existing mineral constituents rather than a molecular replacement of certain substances by others brought in by solutions, and therefore that the magnetite-quartz rocks were very likely siliceous ferruginous sediments to start with. In this connection the evidence yielded by section 1,683 described above is of immense value.

The hypothesis that the magnetite may have arisen through the oxidation of pyrites and that the sediments were originally pyritic in character is a very attractive one, but is attended with difficulties. It first of all requires a reduction of the iron to the sulphide condition, and subsequently its re-oxidation, the latter process being one which is unlikely to have taken place in the zone of anamorphism. The objections based upon the absence of veins of iron ore in the diabase apply in this case still more forcibly, for it is very improbable that the volcanics should have failed to have become impregnated with pyrites, whereas the actual proportion of iron ores in them is always low.

It may be that these deposits were of the nature of bog-iron ore as suggested by Weidman[1] for the origin of certain haematites in Wisconsin; on the other hand, the intercalation of the magnetic rocks, jaspilites, etc., between immense thicknesses of volcanic material is not without significance, and it seems more probable that they were of the nature of chemically deposited sediments. It is interesting at this point to notice that brilliant red jaspers identical with those of the Kraaipan formation have been found interbedded in the volcanics of the Ongeluk division of the Griqua Town series[2] in Hay.

At the same time it must be remembered that the lower zones of the formation were experiencing denudation, while the upper ones were in process of deposition, so that a great amount of sediment composed of small particles of ferro-magnesian silicates and grains of iron ores would have been produced by the weathering and disintegration of the volcanic material, while sedimentation would also have been aided by the incorporation of volcanic ash.

[1] Wisconsin Geological and Natural History Survey. Bull. No. XIII. "The Baraboo Iron-bearing District." 1904.

[2] Ann. Rept. Geol. Comm. for 1906, p. 44-5.

It is important to note that the source of the iron in the Iron-bearing formations of Lake Superior has been largely ascribed to sediment derived from the denudation of the more ancient basic volcanic rocks of that region.

The magnetite-quartz rocks evidently represent the more siliceous sediments, the magnetite-actinolite rocks, those containing a considerable amount of magnesia and possibly also a little lime. Through metamorphism and earth movement they were converted into crystalline schists with crumpled lamination planes. The cherts and jaspilites having been more brittle show less contortion and more fracturing. The diabases and tuffs show the effects of shearing and metamorphism, and are in places converted into hornblende and chlorite schists.

The solutions which circulated along the lines of fracture dissolved and redeposited silica, and oxidised the magnetite to haematite. At a late stage tourmaline, pyrites, and pyrrhotine were introduced, together with a small amount of copper and gold. A section of the country rock (1,672) of the auriferous lode at the Madibi Mine shows that while the octahedra of magnetite are much fractured the crystals of pyrites are unaffected, and that occasionally the latter mineral has crystallised in the cracks developed in the iron ores.

## V. The Transvaal System.

The Black Reef, Campbell Rand, and Griqua Town series are found north of Morokwen, making it evident that these rocks are the continuation of the formations seen near Kuruman though hidden for the most part between these places by superficial deposits. The belt extends east-north-east towards the extreme north-west corner of Mafeking, where the strata are again buried beneath red sand. The dip is to the north-north-west at low angles.

It seems verv probable that the rocks of this system continue beneath the superficial deposits into the Bechuanaland Protectorate. This is very interesting because the rocks of the Transvaal system form in the Marico District[1] a huge syncline which extends westwards into the Protectorate. Little is known about this territory geologically, but Molyneux[2] has given reasons for believing that the synclinal structure continues westwards. Taken in conjunction with the reported occurrences of dolomite limestone over a large area west of Kanya it seems very probable that the Morokwen outcrops constitute a portion

[1] Hatch and Corstorphine. Geology of South Africa, p. 166.
[2] Molyneux. Proc. Rhodesia Sci. Assocn., vol. vi., p. 76, 1906.

of the southern limits of this syncline which is opening out again towards the west.

The geological structure of the divisions of Mafeking and Vryburg is thus revealed as a very flat dome away from which the rocks of the Transvaal system dip at gentle angles. Between Lichtenburg and Vryburg denudation has removed the Black Reef beds, and thus destroyed the regularity of the structure. The outliers of the Black Reef series at Zoete Inval and Blink Klip indicate that the arching up of the dome was not so very considerable.

## A. The Black Reef Series.

A few miles to the north and north-west of Morokwen the rocks belonging to this series crop out at the summit of a sandy ridge of gentle slope. The formation is not at all well exposed, and as the beds dip at very low angles towards the north-west it is difficult to be sure of its exact thickness. Probably it is not more than 30 feet thick at any point; this is much less than at Vryburg or Motiton, but is almost the same as on the Transvaal border east of Mafeking.

The Black Reef rests directly on the granite without the intervention of the volcanics of the Pniel series; the contact is well seen in some prospecting trenches about four miles due north of Morokwen, just within the Native Reserve. In one trench the granite is found traversed by a wide quartz vein, and the overlying Black Reef quartzite is crowded with more or less rounded fragments of quartz and granite, while the matrix is composed of granitic debris. These conglomerates are only present at the base of the formation, and are succeeded by gritty and felspathic quartzites; some soft shaly beds are also present.

A short distance to the north-east, where the formation is exposed in the extreme northern angle of the farm Highlands, the rock is again a hard, light coloured quartzite passing into an arkose and containing pebbles of quartz and granite. On the south side of the farm Kolokolani there is a peculiar exposure as an inlier surrounded by Campbell Rand dolomitic limestones. The pan in which the rocks are exposed is a little over a hundred yards across, and has its floor composed of grey gneissic granite. On the east side the junction of the Black Reef with the latter is well seen. The rock is a dark grey, felspathic, gritty quartzite, adhering firmly to the slightly irregular surface of the granite. The basal layer is in places an arkose, and contains light coloured masses of granitic material, apparently pebbles of granite that were already partially weathered at the time of their entombment in the sediment.

For about twenty miles from this point the formations are buried beneath red sand, until in the Genesa laagte, on the boundary line between the farms Fouché's Rust and Venter's Rust, the Black Reef is again exposed with a dip of about 3° to

the north below the dolomitic limestone. The formation upon which it rests is not seen here, but gneissic granite was proved in a well about five miles to the south.

The strike of the Black Reef series between Morokwen and Fouche's Rust is about east-north-east; this would, if extended, make the formation cross the Molopo in the neighbourhood of Mabul. None of the wells in the river bed thereabout are deep enough to lay bare the underlying formation.

## B. The Campbell Rand Series.

Rocks belonging to this formation cover an area of several hundred square miles north-west of Morokwen, and constituting a belt from 15 to 20 miles wide, succeeded to the north-west by the Griqua Town beds. Small inliers are found amid the red sand east of the main area, *e.g.*, on Mositlani Pan and Quarree Fontein, and in the Genesa laagte on Fouché's Rust.

Due north of Morokwen the dolomitic limestones support a dense growth of hakdoorn (*Acacia detinens*), and their junction with the Black Reef is delimited almost exactly by these thorn trees. This belt of hakdoorn is an extraordinary feature; where the dolomitic limestone is absent or else deeply buried beneath sand, *e.g.*, to the north-east and south-east, its place is taken by other species of acacias. To the south-west it flourishes on the hard calcareous tufa which overlies the dolomite.

The rocks forming the Campbell Rand series are the usual dolomites, limestones, cherts, and occasionally shales that are so characteristic of this formation in Vryburg, Griqualand West, and in the Transvaal. The lower half of the formation is practically free from layers of chert; it is almost entirely composed of limestone and dolomite with thin shaly layers, the last named rather rarely exposed.

A most remarkable feature about the area occupied by these lower beds is the presence of an extraordinary number of the peculiar ridges known as *aars*; reference to these, as occurring in the Kuruman district, has already been made by Mr. Rogers.[1]

These aars form well-defined ridges rising from a few feet up to ten or even fifteen feet above the surrounding flat country; they extend usually in nearly perfectly straight lines.

Sometimes dolomitic limestone is exposed on the ridges, but more commonly the crests are formed by calcareous tufa; invariably they support a dense growth of trees and shrubs. As the belt is followed into an area where the strata become covered up by the red sand, the height of the aars diminishes, they become low, sandy ridges, and ultimately the aar is marked by a regular line of trees only.

The commonest trend of the aars is about north-east, or

[1] Ann. Rept. Geol. Comm. for 1906, p. 64-6.

parallel to the strike of the formation in this locality; sometimes they are so numerous as to be only from 100 to 200 yards apart. They are crossed by other aars, the direction of which is more variable, but which generally lie between north 15° west, and north 30° west. By the intersection of these ridges, hollows are produced, and thus the area is characterised by innumerable small pans with rocky floors; these hold water for a short period after rain.

An excellent view of these aars can be obtained from the summit of the ridge known as Koodoo's Kop, due north of Morokwen. The country becomes more open and grassy, while across it run in various directions long lines of trees forming a geometrical network and appearing as if laid out artificially.

The formation and general direction of these aars is intimately connected with the two main sets of joints in the dolomite limestone, and in the majority of instances they are apparently due to the enlargement through solution of these joints, by which a soil has been produced, thus stimulating the growth of vegetation. In a few instances hard beds have been instrumental in their determination. In other cases their position may have been determined by gentle foldings, for the strata dip away on either side. In only a few examples have the aars resulted from intrusions of igneous rock.

The presence of the network of aars in the sand-covered area to the north-east and south-west may safely be considered evidence of the underground extension in these directions of the Campbell Rand formation.

The upper portion of the Campbell Rand series is characterised by the presence of thick beds of banded or massive cherts, more rarely of calcareous quartzite. The cherts form low ridges, the most prominent being that known as Koodoo's Kop on the north-east boundary of the Morokwen Native Reserve. It rises about 200 feet, and is formed of dolomitic limestones capped by banded and massive white and grey cherts, cherty quartzites, and vein quartz with very little limestone. The outcrop of this prominent stratum can be followed north-eastwards past Nokani Pan to Quarree Fontein, while to the south-west it forms a belt several miles wide crossing the Native Reserve. The dip is at a low angle to the north-west.

Alternations of chert and dolomitic limestone are numerous on Armidale and Tlaping, the beds being near the upper limit of the formation. On each of these farms there is an interesting pan, the floor being formed of nearly horizontal beds of dolomite on which are numerous rock-engravings executed by the aborigines of the district.

The Griqua Town beds form the high ground to the north-west, and though the actual junction with the Campbell Rand series is not very well exposed, the transition appears to be quite abrupt. The best section is seen at the end of a narrow ridge

on Tlaping, practically on the boundary of the latter with the Setaben Crown Reserve.

The Griqua Town beds form a sharp syncline, with dips frequently exceeding 60°. The uppermost stratum of the underlying formation is a massive grey chert more or less banded; it becomes dark brownish-black, and contains a few ferruginous layers higher up, and this is succeeded by the typical red and black banded ironstones of the Griqua Town series.

A similar succession is represented at the beacon common tc Armidale, Stilton and Kglare, where a little infold of banded ironstones rests on massive chocolate-brown and white chert. The formation along the north side of the Morokwen Native Reserve is traversed by a number of quartz reefs which have been prospected on a small scale without any satisfactory results.

## C. The Griqua Town Series.

These beds form a belt with a maximum width of about eight miles north-west of Tlaping, but further to the east the outcrops give rise to a chain of more or less detached hills rising out of the sand and stretching in an east-north-easterly direction almost as far as the Mafeking divisional boundary, a total distance of about forty-five miles. In the opposite direction the ridge breaks off to reappear towards the south-west in the Honing Vley Hills. The area extending westwards to the Molopo is unsurveyed, and very little information is obtainable about it. It appears to be a great tract of flat country covered with thorn bush, and in which the underlying rocks are hidden by calcareous tufa and red sand. Large pans are reported to exist in that direction.

The country extending northwards from these hills of Griqua Town beds to the Molopo is formed of deep red sand, and is covered by extremely dense bush. It slopes gradually to the river. A short description of the physical and geological features of this stretch of monotonous country has been given by Penning.[1]

The strata forming the ridges just referred to belong entirely to the lower division of the Griqua Town series; no outcrops of the Ongeluk volcanics were observed towards the north-west. The strata are as a rule inclined at low angles, generally from 5° to 15°, the dip being usually to the north-north-west. Near Setaben the dips increase in value, and the formation appears to be affected by two sets of folds, one striking north-east and the other north-west very nearly. The strike becomes more easterly as the Mafeking boundary is approached, and in the last exposure in that direction the beds strike practically east and west.

[1] Gold and Diamonds. Chapter V., London, 1901.

The rocks are the usual yellow, brown, and black banded magnetic quartzites, like those described from the Hay and Kuruman districts.[1] They have a great resemblance to some of the banded ironstones of the Kraaipan formation, but are usually yellower in colour and seldom show contorted laminae.

Yellowish brown jaspers are very abundant, red jaspers uncommon; cherty layers and banded ferruginous cherts are very conspicuous, but quartzites are rare. At the south-west corner beacon of the farm Woodborough are a few exposures of reddish weathering sandstone. Thin layers of fibrous crocidolite (asbestos) are not uncommon, *e.g.*, Knysna, Shuenuie, etc., but no attempt has yet been made to work these deposits. The crocidolite is accompanied by its usual oxidation and silicification products.

One of the most conspicuous features in this waterless area is the occurrence after the rainy season of small springs high up on the slopes of these ironstone hills, at points where one would not expect to find anything of this nature.

Their presence is in most cases due to the cementing together with ferric oxide of sand and fragments of banded ironstone lying on the surface of the rock. The breccia thus formed is often many feet in thickness, and water is stored up in hollows and cavities in the deposit. A very good example of this is found on the farm Sweet Water, where a strong supply can be obtained from a reservoir of this sort through a couple of openings not more than two feet in diameter. At the time of my visit the holes had been partly choked up with dead beetles and locusts. The ironstone hills rise out of a sandy grass-covered tract, and in most cases the sand hides all outcrops at the base of the ridges, leaving the rock exposed only towards the summits. At the very eastern end of the chain of ridges there are marked depressions surrounding the hills, and separating them from the flattish tract of sand and bush-covered country both to north and south. These hollows have very probably been produced partly by rain and partly by the wind.

## VI. THE SUPERFICIAL DEPOSITS.

The greater portion of this area is covered by superficial deposits, frequently of considerable thickness, and through which the rocks of the harder formations project in the form of isolated knobs and ridges separated from one another by extensive tracts of approximately level country. This peculiar type of scenery *(Inselberg landschaft* of the Germans) is characteristic of desert regions, and particularly of the Kalahari.

The superficial deposits cannot as yet be sub-divided satisfactorily according to their age, although some are of considerable

[1] Ann. Repts. Geol. Comm. for 1905 and 1906.

antiquity, while others are in process of formation to-day. We have in consequence to classify them according to their lithological characters as follows:—

(1) Sand,
(2) Surface quartzites and ferruginous rocks,
(3) Limestones and associated siliceous rocks.

This three-fold sub-division is not distinctive, for there are frequently transitional varieties.

(1) *Sand.* Over this portion of the Colony sand is the predominating superficial deposit. It always supports a growth of long grass and thorn bush, and is never bare; nowhere are there any sand dunes.

The bulk of the sand is a pale reddish variety, composed of more or less rounded grains of quartz coated with a thin film of iron oxide. In the neighbourhood of the ironstones of the Kraaipan and Griqua Town formations the sand is usually redder in colour; over the Eastern Railway Grant in Mafeking the sand has usually a pale yellowish or pinkish tint.

Where the road crosses the Molopo on the farm Nimrod's Vlei there is exposed some soft sandstone light brown in colour, overlain by red sand and probably produced by the cementing of the latter with limonite and carbonate of lime.

In the vicinity of outcrops of granite and gneiss, or wherever these rocks are immediately below the surface, the sand is usually much coarser in character and contains an abundance of felspar in the form of angular fragments.

Although a certain amount of the red sand has very probably been formed through the disintegration of the granite and gneiss of the district, the felspar being gradually removed by weathering, yet the character of the deposit, and its abundance to the north and west, in the Kalahari, point to the latter region as the source of the great bulk of the sand. The prevailing winds blow from the north and north-west, and the direction of movement of the sand, as shown in the neighbourhood of the pans, is quite in accordance with this view.

In the shallow river valleys, and especially in the river beds, the red tint of the sand is absent, and the latter becomes whitish or grey. This bleaching is probably due to the action of organic compounds by which the ferric oxide is first reduced and then carried off in solution. The same process has gone on during the conversion of the red sand into surface quartzite.

At only a few localities has the thickness of this mantle of red sand been proved in the case of the rising ground between one shallow valley and the next. It appears to vary from a few feet up to nearly 30 feet in depth, and overlies as a rule hard undecomposed granite.

Most of the wells have been sunk in the shallow valleys, and the sections show a variable thickness of sand, sandy wash with

occasional pebbles, and sometimes of clay resting upon a more or less decomposed granite, the last named being the water-bearing formation. Wherever the superficial deposits attain any thickness the lower portions of the sand cover has as a rule been converted by the deposition of silica into a more or less compact rock to which the term "surface quartzite," although from its position rather inappropriate, will apply.

(2) *Surface quartzites and ferruginous rocks.* In a few places the sand is firmly cemented together by means of ferric oxide to form a hard dark brown ironstone deposit. This is generally only found where the sand rests upon the Kraaipan formation, *e.g.*, at Logaging, and the source of the iron is therefore obvious.

More commonly the sand grains are bound together with a siliceous cement and a rock of intense hardness may be produced thereby.

Such rocks have been generally termed "*surface quartzites,*" a name which is unfortunately unsuitable for several reasons. The expression "chalcedon-sandstein," used by Passarge, though less objectionable, fails to convey the exact meaning when the siliceous cement is opaline and not chalcedonic silica. It seems a pity that the term "silcrete," proposed by Lamplugh to indicate rocks of this nature, has not been more generally employed.

The surface-quartzites are not all of the same age, and as they usually occur in more or less isolated patches, it is not often that good evidence is found to prove their relative antiquity.

In several of the river valleys exposures of surface-quartzites exist that are presumably of similar age, for in each case they are underlain by peculiar soft red marls.

These quartzites and marls are typically developed along the Molopo, between Pitsani and Mabul, for a distance of a little over thirty miles, but are found as well at Steil Hoogte on the Setlagoli River, at Tlaping, at Vaalpens Spruit, and at the Wegdraai in the Genesa Valley. The distribution of these deposits is indicated in the accompanying map (fig. 2).

About five miles below Pitsani the calcareous tufa on the banks of the river becomes harder and acquires a pink colour. It gradually passes into a whiter somewhat calcareous surface quartzite, weathering into hard jagged masses which make travelling along the river bank somewhat arduous. The deposit forms a terrace rising from 20 to 25 feet above the bed of the Molopo, and its surface is strewn with pebbles of magnetic quartzite, chert, jasper, quartz, chalcedony, and sometimes diabase and quartzite. A short distance away from the river the ground rises and all is hidden beneath red sand.

A little before reaching the Mobelo Spruit the quartzite terrace becomes higher and better developed, so that the river flows in a low gorge varying in width from a few hundred up to about one thousand yards.

The quartzite cliffs extend up the Mobelo and Logogani spruits and down the Molopo, the distance between them continually diminishing until below Makgori the river channel is sometimes less than 100 yards wide, while the banks are often over 40 feet in height. At Kwedi the river banks are formed by an outcrop of banded ironstones, but the quartzites reappear further down and also along the last five miles of the Setlagoli River, and the low cliffs continue as far as Mabul. Below this point the river banks have a gradual slope, and there are no outcrops of any hard material; the wash in the river bed contains small fragments of tufa and quartzite, but away from it there is nothing except red sand.

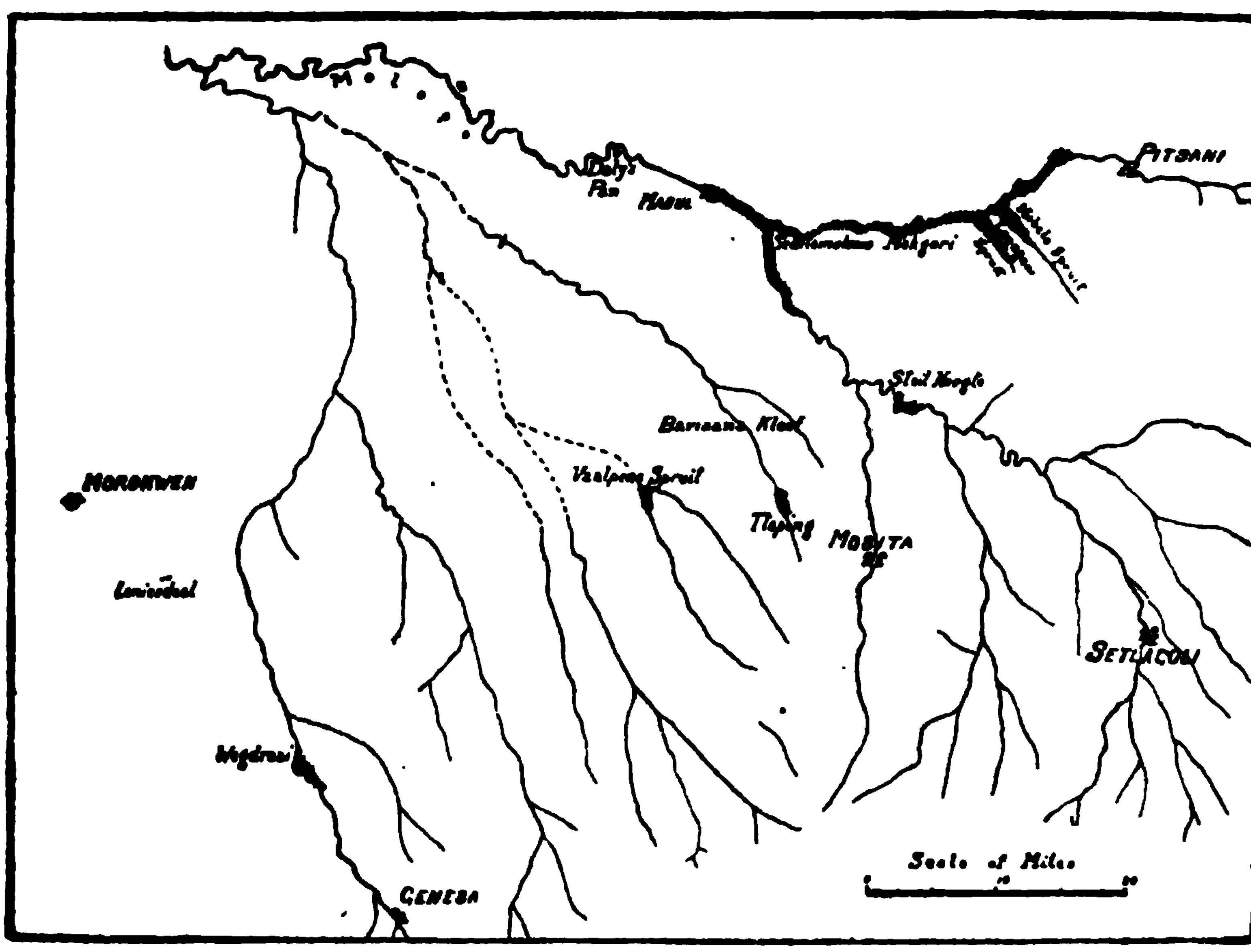



FIG. 2.—Map showing the distribution of the surface-quartzites overlying the red marls.

The quartzites vary in colour from white or grey to pink and sometimes to brown, as on the Logogani Spruit, but the brown tint here is only a surface phenomenon. In places they are fine-grained, in others gritty, and sometimes they are very pebbly, *e.g.*, at Sedilamolomo; in places they are more like sandstones, at others they are greatly silicified, being traversed by veins of opaline silica, or containing druses lined with semi-opal.

A thin section (1,697) from a grey compact variety on the Setlagoli River just above its junction with the Molopo shows under the microscope the following features: The larger grains are usually rounded, while the smaller ones are sub-angular or angular. Quartz is the most abundant constituent; there are

also grains of orthoclase, plagioclase, and microcline felspar, and chert together with granules of epidote and sphene. A few of the grains still retain, or have only partially been deprived of, a coating of limonite, showing that during the formation of the quartzite the mineral grains have had their thin enveloping films of iron oxide partially dissolved away. The cement consists of colourless isotropic silica (opal), but wherever the spaces between the grains have been larger than usual there occur druses lined by or filled with chalcedonic silica.

The surface-quartzites rest upon a deposit, which is but seldom exposed, and then usually only where storm water has excavated little ditches, as for example along footpaths. This formation consists of pink and red marls, and clays hard when dry, but crumbly when moist. They remind one of the red beds of the Stormberg formation, but include no layers of sandstone or limestone. No bedding can be made out, but as they are visible at intervals over a distance of about six miles, from a little to the east of the Mobelo Spruit to a point a little east of Makgori, it is probable that they lie nearly horizontally and conformably beneath the quartzites.

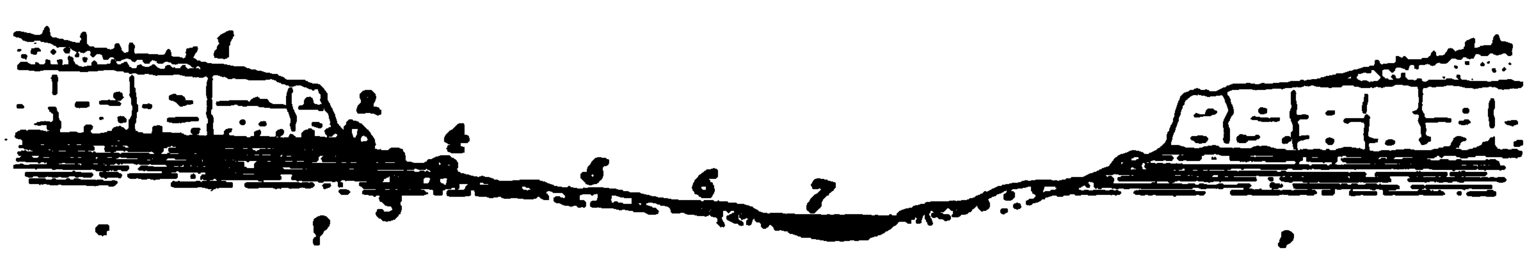



FIG. 3.—Section across the Molopo at a point midway between Pitsani and Makgori. 1, Red sand; 2, surface quartzites; 3, red marls; 4, fallen blocks of surface-quartzite; 5, surface quartzite and breccia, with fragments of 2; 6, light grey and dark grey soil; 7, black alluvium.

The base of the marls is never seen, but in several places they must have a minimum thickness of about 20 feet, and probably much exceed this.

Under the microscope the marl shows abundant minute elongated crystal aggregates of calcite, shaped very much like rice-grains, small fragments of quartz, and some pinkish clayey matter. No diatom remains were noticed in the material.

The general succession along the Molopo is shown in fig. 3. Resting on the sloping surface of marls are blocks of quartzite, which have fallen down from the cliffs. Where these become numerous and repose upon a less inclined surface they have become cemented together with sand and silica, and form a cake of siliceous breccia (5) in which the fragments of the older quartzite are easily recognisable. This younger formation is very well seen at a point a little to the east of the Mobelo Spruit.

The quartzites and marls are present along the Setlagoli River on the farm Steil Hoogte for a short distance. The former are often calcareous and pebbly, the latter are thin and rest directly upon gneissic granite. At Tlaping, west of Mosita,

the granite disappears a short distance down the laagte, and on either side of the valley appear surface quartzites from 20 to 25 feet in thickness, overlain by red sand. The formation extends northwards for several miles, and consists of a hard cavernous rock of varying colour—white, pink, red, etc.—the cavities being lined with opaline silica. There are beautiful druses coated with pale bluish opal, and veins of the same material ramify through the rock.

A small well in the extreme north-western corner of the farm at the foot of the little cliff shows pink and red gritty marls.

A couple of miles further down on Buffels Bosch a shallow pit in the lowest part of the laagte proved the existence of a brownish compact quartzite below whitish river sand, while on Baviaan's Kloof a well passed through alluvium and calcareous tufa into a similar quartzite full of tubular hollows containing soft white sand. These quartzites are undoubtedly much more recent than the siliceous rocks overlying the red marls.

On Vaalpens Spruit a hard siliceous rock like that on Tlaping crops out at the junction of two laagtes. The material is full of cavities and hollows, and superficially resembles to a great degree a vesicular lava. Some portions are white, others pink, and frequently the rock contains pebbles of quartz, banded ironstone, etc.; it is much veined or has its cavities lined with opaline silica. There are no exposures of the marls, but they are in all probability present below the siliceous rocks.

In the Genesa Valley, between Lancewood and the Wegdraai, are similar quartzites reddish in colour and full of peculiar tubular hollows from one to two inches in diameter ramifying through the rock. The well at the Wegdraai passes through tufa, quartzite, and calcareous silicified arkose into granite. An old well two hundred yards to the west proves the existence of red marls below the siliceous deposits.

*Distribution of the Surface-quartzites and marls.*

The occurrences just described appear only in the valleys where the mantle of sand has been removed or has been prevented from forming. How far these deposits extend beneath the sand and away from the rivers is a matter of uncertainty. It is clear, however, that they do not occur to the south-east of a line drawn from Pitsani through Mosita to Genesa, while boreholes and wells have shown that they are not represented in the area just east and north-east of the Wegdraai.

At Leniesdeel, between the Wegdraai and Morokwen, a well over 60 feet deep has penetrated red sand, calcareous tufa, and sandstone with hard quartzitic portions without proving the

underlying formation. This may possibly be an extension of the quartzites of the Wegdraai.

Again, on the Molopo at Daly's Pan, below Mabul, a well has revealed hard quartzites below sand and tufa in an old cut-off loop of the river.

The quartzites and marls are never found on the high ground, *e.g.*, above about 3,750 feet above sea level, and fall to about 3,550 feet at Mabul. Wherever ridges of hard rock are found, the continuity of the recent formation is broken, *e.g.*, at Kwedi and again between Logaging and Steil Hoogte.

It seems most probable that the marls and quartzites were deposited in a series of valleys, although it is not improbable that their former distribution was much more extensive, for it is clear that in most places the rivers have cut down through the hard quartzites into the soft marls. From the variation in altitude of the different exposures it is unlikely that they are of lacustrine origin however.

The origin of the quartzite will be discussed after a consideration of the calcareous deposits.

### (2) *The Calcareous and Associated Rocks.*

The purest variety of calcareous tufa is that which occurs in some of the pans (the *pfannenkalktuff* of Passarge), especially well seen both at Kolokolani and Mositlani Pans north-east of Morokwen.

It forms fairly well defined superimposed layers, varying in thickness from a few inches to a couple of feet, and although snow-white externally possesses a rather drab tint on freshly broken surfaces.

At Mositlani there are at least five of these layers which are nearly horizontal; at Kolokolani the layers dip inwards towards the centre of the pan. The tufa often contains the remains of fresh water mollusca.

The layers are peculiar in possessing numerous narrow perforations extending nearly vertically downwards. They may possibly owe their origin to roots of grasses.

A porous tufa of somewhat similar nature is found in the beds of some of the laagtes between Genesa and Mosita, and sometimes contains shells of mollusca, *e.g.*, at Khudungkwani.

A wide area over the north-western portion of the Morokwen Native Reserve is covered with hard calcareous tufa, somewhat siliceous in places. The deposit is largely due to the presence below ground of the limestones and dolomites of the Campbell Rand series.

At Morokwen, calcareous tufa is found intervening between the granite and the cover of red sand, and is especially well seen at the eastern end of the pan. The drainage from the area round about is directed towards this depression, making its

way along the upper surface of the granite, and thus the formation of tufa beneath the sand is brought about. The water entering the pan is perfectly fresh, while that found in the pan itself is salt.

East of Morokwen, patches of hard tufa project through a thin cover of red sand, but beyond the boundary of the Reserve the latter hides the calcareous deposit. In the laagte on Donegal, a well shows tufa containing veins, layers, and irregular masses of chalcedonic silica varying in tint from black to colourless. At Goed Hoep (Groen Kooi) are wells in calcareous tufa and quartzitic rock with similar streaks of chalcedony, some of which is transparent and either colourless or amber-coloured.

Numerous small implements were obtained from the ground thrown up out of these shallow wells and most of them were made of this chalcedonic silica derived from the veins in the tufa. The amber-coloured material is identical with the stuff from which so many of the implements found at the Victoria Falls have been manufactured.

*Origin of the Silcrete Rocks.* A complete description of similar rocks from the Kalahari and of their petrographical characters have been given by Passarge[1] and Kalkowsky.[2] Speaking roughly, the rocks are made to fall into two types:—(1) those in which the grains have been cemented together by silica *(eingekieselte gesteine)*, and (2) those in which calcareous material has been replaced by silica *(verkieselte gesteine)*. These two divisions correspond practically to the surface-quartzites and to the silicified tufas respectively. In the one case the solutions have merely deposited silica in the spaces between the sand grains, in the other a certain amount of calcareous matter has been removed by solution simultaneously with the cementation.

It is easy to obtain hand specimens in which both these processes have taken place, and the field evidence shows that the variable nature of the deposits is due to the silicification of materials which range from sand through sandy tufa into a pure calcareous deposit, while not infrequently the rocks are pebbly in character.

Since these silcrete rocks are commonly underlain by soft sands, clays, or marls, and do not rest directly upon the underlying formations, it is clear that the process of silicification does not take place in the materials below but is due to water circulating through the sand and tufa at a depth below the surface where the effect of evaporation is becoming appreciable. The quartzite will thus develop by the gradual induration of the base

---

[1] S. Passarge. Die Kalahari. Berlin. 1904.

[2] E. Kalkowsky. Die Verkieselung der Gesteine in der nördlichen Kalahari. Mitt. K. Min.-Geol. Museum. Dresden. 1901.

of its cover of sand in the way which Lamplugh[1] has suggested in discussing the silcrete deposits of the Zambezi Basin.

Many of the quartzites are certainly of considerable antiquity, but the formation of similar rocks may be still going on at the present day.

## VII. The Development of the Physical Features of the Area.

Passarge has dealt very fully with the question of the origin of the physical features of the Kalahari, and has brought forward a great number of facts pointing to considerable climatic changes in the past.

Much of his description applies to the area under consideration, but the inferences which I have drawn as regards the development of the area and the climatic variation differ to a certain extent from those of Dr. Passarge.

As already remarked, the area shows that peculiar type of landscape termed "*Inselberg-landschaft*," the origin of which has been fully discussed by Passarge.[2]

There is some uncertainty, however, in this area as to whether the features had not been developed to a considerable degree in Pre-Dwyka times. The chain of hills north-west of Morokwen possesses beautifully smoothed and rounded outlines which recall most strikingly the Griqua Town hills between Griqua Town and Prieska, where the covering of Dwyka tillite has been recently removed. The discovery of Dwyka tillite by Mr. Rogers[3] on the Molopo near Kolingkwani, and by Mr. Molyneux[4] at Mochudi and Palapye, renders it not improbable that a vast area in Bechuanaland has been stripped of its covering of Karroo beds only in very late geological times. Some of the ridges may, therefore, owe their main features to pre-Karroo denudation, the minor sculpturing being due to sub-aerial erosion at a much later period.

That this area has been subjected to active river erosion at a late period in the geological scale is indicated by the existence of banks of coarse gravels[5] between Mafeking and Madibi (K. 14), and again about 12 miles further to the west (K. 11). These fluviatile deposits attain an altitude of 4,203 feet above sea-level at the former locality, and 4,155 feet at the latter, and are, therefore, considerably above the level of the country round about. It is evident that these gravel patches are outliers of a former and more extensive alluvial deposit laid down upon a peneplain that extended from the Transvaal over Mafeking with a gradual westerly slope.

---

[1] G. W. Lamplugh. Quart. Journ. Geol. Soc., Vol. 63, p. 199, 1907.

[2] S. Passarge. Die Inselberglandschaften in tropischen Afrika. Naturwissenschaftliche Wochenschrift. No. 42. Jena, 1904.

[3] See p. 81.

[4] Molyneux. Proc. Rhodesia Sci. Assocn., Vol. VI., pp. 78-84. 1906.

[5] Ann. Rept. for 1905, p. 255.

The whole of the drainage from this quarter converges towards Pitsani, and passes through a great gorge about half a mile in length and in places nearly 200 feet deep, cut in a ridge of hard magnetic quartzites and cherts. This barrier reaches the altitude of 3,924 feet above sea-level, and must have been instrumental in protecting the area to the east from vigorous erosion. The natural conclusion, therefore, is that the high level gravels were deposited at a period when the Molopo had just commenced to cut its way through this obstacle.

The laying down of the gravels, the cutting of the gorge, and the consequent erosion of the drainage basin must have been accomplished during a period of a higher rainfall than the district now possesses, for at the present time it is only on rare occasions that the Molopo flows for more than a week at a time during the wet summer season. The existence of an early period of heavy rainfall *(pluvialzeit)* seems, therefore, fairly well established.

The red marls, overlain by the surface quartzites and siliceous conglomeratic rocks, commence immediately below the great gorge at Pitsani, their position indicating that they were formed after the cutting through of the barrier. They appear to have been deposited in the ancient valley of the Molopo, and may be regarded as a thick stratum of calcareous mud that has been covered over with sand and gravelly material, the latter having been subsequently indurated. The exact reason for the formation of these deposits is not quite clear. It may be that the material was laid down owing to increase of load from growing tributaries, coupled with the decrease of gradient due to the cutting of the gorge. On the other hand similar quartzites and marls, though of less thickness, occur in valleys having much smaller drainage areas.

It may, therefore, be that the clays, sands and gravels accumulated in the valleys consequent upon a period of diminished rainfall. It must be noted that although the surface-quartzites are frequently conglomeratic, and therefore in great part of fluviatile origin, nevertheless there enter largely into their composition well-worn grains of sand, evidently wind-borne.

The hypothesis of a period of lesser rainfall would at the same time account for the intense silicification of the material and its conversion into quartzite; still, it is not unlikely that the process of induration was again in action at a much later period.

The cutting through of the quartzites until the softer marls, and in some cases the bed rock, became exposed, indicates a renewal of river activity that can only be accounted for by a recurrence of humid conditions. Considering the extremely low gradients (about 3 feet per mile) of the rivers for several hundreds of miles westward, it is clear that this renewed activity cannot be accounted for by an increased slope of the river bed brought about by tilting of the drainage area.

The initiation of this second pluvial period is marked by the occurrence of low-level gravels on the Setlagoli River between Buck Reef and Logaging, on the Molopo just below Pitsani, and by the presence of old loops or "cut-offs" along the river below Mabul. A fine example of a loop now above the level of the river bed is known as Daly's Pan.

Most of the rivers do not seem to have been able to clear out the deposits that filled in their former channels; if ever that were the case they have since been unable to cope with the products of sub-aerial weathering and the quantity of blown sand from the west.

All the larger rivers rise in areas where the hard rocks are frequently exposed, but the small valleys exist entirely in sand-covered country. In the rainy season the rivers flow for a short time, and ultimately the water soaks into the bed of the river and percolates along the sand of the valley bottom. Many of the rivers exist merely in name; for example, the Matlapin Spruit. Although over 40 miles in length, water never flows along its middle reaches. The bed is being obstructed by the accumulation of wind-borne sand and rain-wash, so that in several places the gradient of the valley bottom is reversed.

At the present day the rainfall is high enough to enable vegetation to fix the mantle of red sand, otherwise the rivers would long since have had their channels obliterated. As it is, the disappearance below ground of the surface quartzites on the Molopo, below Mabul, is proof of the invasion of the drainage area by red sand from the Kalahari region of the north-west.

# GEOLOGICAL SURVEY OF PORTIONS OF HOPE-TOWN, BRITSTOWN, PRIESKA AND HAY.

By ALEX. L. DU TOIT.

The northern region is constituted by the Kaap plateau, with an altitude of about 4,000 feet above sea level, terminating abruptly a little to the north-east of Read's Drift.

To the west are the Griqua Town Hills, or Asbestos Mountains, forming a chain extending northwards from Prieska through Hay, and usually exceeding the altitude of 4,000 feet above sea-level. This country north of the Orange River is often rugged and stony, with a fair amount of vegetation, principally composed of the various smaller species of acacias.

The Orange River flows in a winding gorge, which is nearly always at a considerable depth below the surrounding country; only at the junction with the Vaal River and again near Prieska does its valley widen out to any extent. The gradient of the river is very small, and its altitude near Prieska is only 3,020 feet above sea-level. With such a considerable fall from the Asbestos Mountains to the Orange River there are in consequence a number of tributaries flowing southwards to the latter, the most important being the Sand River which rises a little to the north of Griqua Town.

The central region comprises the northern portion of Hopetown and the eastern portion of Prieska, and is a slightly undulating and very monotonous tract occupied by the Dwyka formation, and covered with little bushes a few feet in height, with here and there a patch of thorn bush or grass land.

In the south we enter typical Karroo country—flats with small Karroo bushes and more or less conical or flat-topped hills of shales capped by sheets of dolerite.

The only river of importance in this region is the Brak River, which, with its various tributaries, takes its rise in the area around Britstown and De Aar.

The northern portion of Hopetown is untraversed by stream courses, there being only very shallow depressions leading either to the Orange or Brak Rivers; commonly the drainage is directed into one or other of the numerous pans, which are a conspicuous feature of this part of the district.

*Geology.* The geological succession is as follows:—

| | | |
|---|---|---|
| Recent and Superficial Deposits... | | Alluvium, sand, calcareous tufa and gravels. |
| Karroo System | Ecca Series ... ... | Flaggy shales and shales with calcareous concretions. |
| | Dwyka Series ... ... | 2, Shales with "White Band." 1, Boulder Beds. |
| Transvaal System | Griqua Town Series (Lower) | Banded ironstones and jaspers. |
| | Campbell Rand Series... | Limestones, dolomites, cherts and shales. |
| | Black Reef Series ... | Quartzites and shales. |

| | | |
|---|---|---|
| Vaal River or Ventersdorp System | Pniel Series ... ... | 2, Diabase, amygdaloid and breccia.<br>1, Quartzites. |
| | Kuip Series ... ... | Diabase, amygdaloid, arkose, chert, and limestone. |
| | Zoetlief Series... ... | 2, Rhyolites and felsites.<br>1, Grits and conglomerates. |
| | Granite and gneiss. | |
| | Schists included in the granite and gneiss. | |

(The wavy line indicates an unconformity.)

There are a number of basic intrusions consisting of diabase and dolerite, the latter forming more or less horizontal sheets in the Karroo rocks. There are also several pipes and fissures filled with Kimberlite (blue-ground) and sometimes carrying diamonds.

## II. The Granite and Older Schists.

Immediately south-east of the T'Kuip Hills at Omdraai's Vlei the granite has been brought to the surface by an anticlinal fold trending north-east, and evidently the extension of that affecting the rocks of the Doornberg. The main mass of the granite extends northwards from Roode Poort for a distance of ten and a half miles, and has a breadth of about six miles, the Brak River crossing it from south to north. That it has a much greater extension towards the south-east is shown by the numerous little inliers in the Dwyka conglomerate, notably on the farms West Prairie and Ruitjes Vlakte, while some outcrops appear close to the western extremity of Beer Vlei.

The granite is mostly a pink, medium-grained gneissic variety with foliation planes striking approximately north-east, and dipping towards the south-east. On Roode Poort the strike of the foliation is nearly east and west.

Porphyritic varieties are present, but are not very common; pegmatite and aplite veins are fairly abundant, and epidotised bands are frequent. On T'Kuip (East) some of the pegmatites carry fluor-spar. The granite is traversed by reefs of quartz, occasionally carrying a little copper, and by dykes of diabase and diorite.

On Lange Dam, nearly midway between T'Kuip and Hopetown, granite appears from below the Pniel quartzites in two little anticlines. The bulk of the rock is a fairly fine-grained pink gneissic variety, commonly a biotite-gneiss, rich in microcline felspar. The foliation planes are vertical, and strike about north-east.

Granite occurs in a similar manner a little west of Swingel's Pan, north of Beer Vlei.

As in the Mafeking Division so here also the granite and gneiss contain numerous inclusions of amphibolitic schists as

patches and lenticles traversed by veins of granitic material, both along and across their foliation planes, and showing all stages in the process of absorption with the production of banded hornblendic gneisses. These rocks are especially well seen along the banks and in the bed of the Brak River at the foot of the T'Kuip Hills.

A section (1,912) of one of these schist inclusions from the granite on Ruitjes Vlaakte shows the following features under the microscope. The rock is formed of actinolitic hornblende, usually nearly colourless, but sometimes pale greenish and pleochroic, abundant crystals of epidote with a smaller amount of zoisite, and a groundmass of colourless felspar containing little granules and prisms of epidote. It could well be termed a schistose diabase. A band, rich in quartz and orthoclase felspar, indicates an accession of granitic material, and in its neighbourhood the actinolite has a tendency towards idiomorphic outlines, while the epidote is aggregated together to form larger areas.

## III. The Vaal River or Ventersdorp System.

The diabases and amygdaloids with their basal quartzite formation (Pniel Series) were in the course of the survey traced as a chain of more or less detached areas surrounded by Dwyka tillite stretching from the Orange River in the vicinity of Hopetown past Beer Vlei to a point a little south of T'Kuip.

In the last Annual Report it was noted that the Pniel series overlay unconformably at Klokfontein, Modder River, and in the Kimberley mines certain rhyolites that were grouped with the Zoetlief series. Similar acid volcanics appear as a chain of inliers in the Dwyka arranged along a straight line extending westwards from a point a little south-east of Strydenburg through Beer Vlei to T'Kuip.

Although no actual contacts with the Pniel series are found, there can be no doubt that the acid lavas are an older and unconformable formation, and hence will correspond to the Zoetlief series of Griqualand West and Vryburg.

In the T'Kuip Hills the gap between these two formations is partly bridged over by a series of basic volcanics with interbedded arkoses, which appears to be unconformable both to the older and to the younger formations. To this group a distinctive name, the Kuip Series, has been given. Their existence had been recorded in the Report for 1899, but the relationships of the various volcanic rocks were not determined at that time.

### A. The Zoetlief Series.

At T'Kuip this series can be divided into an upper group of acid volcanics and a lower and less persistent group of conglomerates, arkoses and breccias, with occasional lava flows.[1]

[1] A. W. Rogers. Ann. Rept for 1905, p. 150.

Towards the southern end of the T'Kuip Hills, at a point about three-quarters of a mile north of the beacon belonging to Maritz Dam, the rhyolites rest directly upon the granite. About a quarter of a mile further on, the volcanics form a

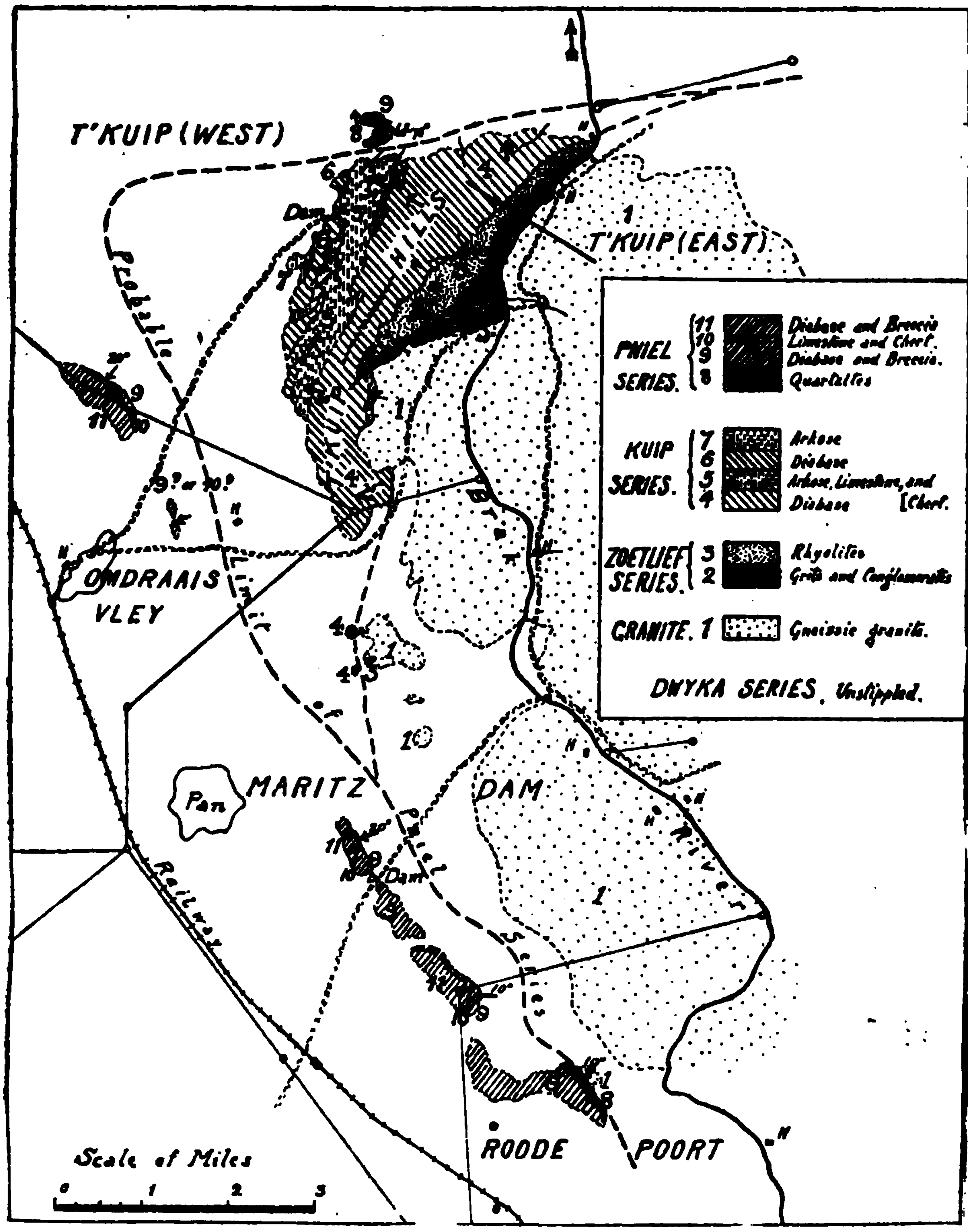



FIG. 1.—Geological map of the T'Kuip Hills.

small isolated eminence, at the base of which appear some hard green quartzites.

These rapidly thicken towards the north, coarse grits and arkoses making their appearance accompanied by breccias, tuffs and some thin bands of dark green volcanic rock.

The thickness of the sedimentary group probably does not exceed 300 feet; at the drift the existence of two parallel

strike faults, with a total downthrow to the east of about 150 feet, causes the thickness to be apparently much greater. This zone can be followed down the Brak River for several miles, but at T'Kuip (West) farmhouse, the last point where they can be seen and measured, they do not exceed 60 feet in thickness.

The gritty and conglomeratic rocks are dark in colour, and do not part readily along their planes of stratification; they weather into great rounded blocks and masses of very striking appearance.

The base of the series is very well seen in the bed of the Brak River a little below the drift. The surface of the granite is somewhat uneven, and the conglomerate overlying is coarse in places, the inclusions consisting of blocks of granite and occasionally of amphibolite.

In the higher beds the pebbles seldom exceed eight inches in diameter, and are usually well worn. They consist of quartz, quartzite, granite, and aplite, and are set in a groundmass composed almost entirely of granitic debris. A section of the pebbly arkose (1,908) shows under the microscope a rock composed almost solely of fragments of quartz and orthoclase and microcline felspar, together with a small amount of chloritized mica; the proportion of matrix is extremely small.

A section (1,907) of one of the dark green volcanics, interbedded in the arkoses, proves it to be an andesitic lava, having phenocrysts of oligoclase felspar set in a groundmass crowded with little prisms of the same mineral; the ferro-magnesian minerals have been completely altered.

These grits and conglomerates occupy the same position, both as regards the granite and the rhyolite, as those which have been cut in the main shaft of the Kimberley Mine below the 2,520 foot level.[1] Lithologically they resemble the latter very much indeed, having the same assemblage of pebbles. Both at Kimberley and at T'Kuip the sedimentary group thins out in a short distance, so that the rhyolites rest in places directly upon the granite.

The rhyolites are compact rocks not often vesicular, but showing a more or less banded character, which appears as a rule to correspond to the actual bedding planes of the lava flows. Some abrupt contortions of the banding may, however, be merely fluxion structures like those in the rhyolites at Klokfontein.

The lavas belonging to this formation, which occur at Bidouw's Kuil and Vilet's Kuil, on the north side of the Beer Vlei, were described in the 1899 Report under the name of amygdaloidal felsites. All the outcrops are in the form of hillocks with rounded outlines rising from a flattish tract of Dwyka.

Dips are difficult to make out, for the banding is, in certain

[1] Ann. Report for 1906, p. 95.

cases, due to igneous flow, while, in addition, the rocks may be broken up by well-developed joints. Here and there layers of amygdaloidal or brecciated lava occur, and though the bands are impersistent they indicate a general northerly dip, probably accompanied by a certain amount of folding.

At Bidouw's Kuil the lowest lavas on the edge of the vlei consist of massive rhyolites, sometimes brecciated. Further north they become more amygdaloidal and apparently less siliceous, and consist of felsitic lavas often very vesicular and slaggy, and containing large quartz and chalcedony geodes. There are alternations of light and dark coloured lava. The same succession is found at Vilet's Kuil. The knobs of rock on the south-east side of the farm consist almost wholly of compact or brecciated and veined rhyolite, often with large porphyritic felspars. The northern outcrops are massive banded rhyolites, and the extreme north-western hummock is composed of darker amygdaloidal rock.

From the outcrops on Bidouw's Kuil and Vilet's Kuil the surface of the Dwyka tillite rises gradually for a distance of from one to three miles, and then Pniel lavas underlain by the quartzite group make their appearance, and dip at a low angle to the north.

The easternmost outcrop of the rhyolite was found in the midst of the Dwyka series on the farm Wonderdraai, a few miles south-east of Strydenburg and 34 miles from T'Kuip.

The rhyolites are pale greenish rocks containing blebs of quartz and commonly phenocrysts of felspar. In thin section they are found to be very much altered as a rule. The felspar phenocrysts consist of orthoclase and plagioclase, the latter frequently predominating. Usually they show alteration to a mixture of quartz, mica ,and chlorite ,but sometimes they are wholly or partially replaced by calcite. The ferro-magnesian constituents are hardly represented ,and then always by alteration products such as chlorite. In one specimen from Vilet's Kuil there are good pseudomorphs in isotropic yellowish serpentine after some mineral which was probably enstatite.

The groundmass is usually considerably altered, especially through silicification, but many examples show some colourless or brownish glass, and there are very fine perlitic varieties. The amygdales are usually filled with quartz and chalcedony.

The rhyolites frequently show the effects of movement by which the blebs of quartz have been shattered and the broken portions separated from one another. It is difficult to decide whether this has resulted through the brecciation or whether it has been caused by subsequent earth-movement. The abundance of brecciated rock and the presence of true tuffs points to the former of these two possible causes as the most likely one, but it is not improbable that the structures owe something to the second as well.

The common occurrence of plagioclase felspar in the acid

lavas indicates perhaps that some of the rocks are more closely allied to the quartz-andesites (dacites) than to the rhyolites.

Some of the lavas, especially in the upper portion of the series, contain no free quartz, and may be termed felsites or trachytes; they may also have plagioclase felspar in addition to the orthoclase.

The presence of lavas of intermediate composition in the upper portion of the volcanic series at Beer Vlei affords another parallel with the succession at Zoetlief in Vryburg and in the Kimberley mines.

The thickness of the volcanic group at T'Kuip is probably about 500 feet, but this appears to be much exceeded at Vilet's Kuil; at the latter place neither the base nor the summit of the formation is exposed.

On Maritz Dam, a few miles south of the extremity of the T'Kuip Hills, there is a rather peculiar occurrence of rhyolite, which is of interest for several reasons.

The volcanics form a little hillock rising from a flat of gneissic granite, and the junction of the two rocks is visible on the north side.

The exposure is about 250 feet long and 50 broad, with longer axis striking nearly east and west, and the rhyolites dip inwards from the north and from the south at a high angle.

The structure may be explained as a synclinal outlier of the rhyolites, but it is quite possible that it represents a volcanic neck from which the lavas of the Zoetlief series issued, the banding of the rhyolites representing fluxion structures parallel to the walls of the pipe. This seems a not-unlikely view, for nowhere have there been found any quartz-porphyry dykes which could account for these great rhyolite flows, nor, with this exception, do there appear to be any pipes corresponding.

Whether the occurrence is a pipe or a synclinal basin is immaterial, however, for in either case it makes it probable that at one time the Zoetlief volcanics were continuous between this point and the T'Kuip Hills.

Now about a quarter of a mile to the north the Kuip series rests directly upon the granite, while about 150 yards to the west of the rhyolite hillock is another little patch of basic lavas and breccias, the intervening ground being covered with soil and probably underlain by the Dwyka conglomerate.

It is perfectly clear then that the Zoetlief series has suffered considerable denudation prior to the formation of the Kuip series.

## B. THE KUIP SERIES.

As shown in fig. 1, the rocks of this group succeed the rhyolites and build up the central and western portions of the T'Kuip Hills.

The formation consists of diabase and amygdaloid, with some thick intercalations of arkose, pebbly grit, sandstone, flagstone, limestone and chert. The beds have a constant dip of from 15°—40° to the west-north-west, and where most fully developed the formation must have a thickness of at least 1,500 feet.

The two southernmost outcrops on Maritz Dam have already been referred to. One of these is merely a little patch of volcanics surrounded by Dwyka, but the other consists of diabases and breccias underlain by about 50 feet of arkose, grit, and flagstone resting upon gneissic granite, and dipping at from 30°—45° to the west.

At a point a little north of the T'Kuip—Maritz Fontein beacon the diabases rest apparently upon the granite, but a little further north the Zoetlief rhyolites make their appearance, and underlie the diabases. The lowest flow of diabase rests directly upon a peculiar bed of brecciated rhyolite for some distance, until a strike fault brings up the granite almost to the level of the diabase.

From this point the thickness of rhyolite below the Kuip diabase increases from 150 feet to about 500 feet, attaining its maximum value below the highest point of the ridge; further north, the acid lavas become thinner. The rhyolites thus form the eastern slopes of the hills, and the diabase the high ground to the west.

The junction of the basal flow of the Kuip series with the rhyolites is not clearly exposed anywhere, and an unconformity can only be inferred from the fact that the former comes successively into contact with different lithological types of rhyolite, the dip and strike of the two formations being approximately the same.

At the north end of the T'Kuip Hills the junction is not clearly exposed, but in a little kloof about one mile to the south of that point there intervenes between the two groups of rocks a bed of hard green diabasic tuff from eight to ten feet in thickness.

The rocks forming the lower portion of the Kuip series are almost entirely diabases and amygdaloids, indistinguishable in hand specimen from those of the Pniel series; volcanic breccias are less common, however, than in the latter.

A thin section (707) from the south end of the hills shows a rock containing oligoclase felspar in phenocrysts and microlites and isotropic serpentine, probably pseudomorphous after enstatite, set in a groundmass which must have been glassy originally. The amygdales are filled with calcite and serpentine.

Low down in the series on the south-east side of the hills is a thin intercalation of arkose containing pebbles followed by porphyritic lavas.

The first big zone of sediments is found on the west side of the hills, where it gives rise to a belt of lower lying ground. At the northern end of the belt, where the rocks are well exposed,

the base of this sedimentary zone is formed by a thick bed of arkose resting upon a very vesicular lava flow. Hollows in the latter have been filled with gritty material, while the arkose contains angular fragments of diabase up to six inches across. Above the arkose come hard cherty flags, succeeded by a series of brown weathering limestones associated with cherts. These limestones run evenly with a westerly dip, but die out one by one as they are followed towards the south end of the hills. They are overlain by green and black cleaved flinty rocks, and these in turn by a thick bed of arkose.

This group of sediments is about 450 feet in thickness, but near the south-west end of the hills it is split up by two wedge-shaped sheets of diabase, and its thickness increased to over 600 feet. The rocks are chiefly arkoses, which weather unequally and produce a light sandy soil from which project large rounded hummocks of the more indurated material.

The second volcanic zone probably does not exceed about 150 feet in thickness, and forms the westernmost chain of kopjes in the T'Kuip Hills. The lavas dip westwards at a moderate angle.

The second sedimentary group was only found on the slope at the foot of ridges where the beds are partly hidden by sandy soil. The strata consist of arkoses several hundred feet in thickness.

The upward succession is as follows:—Dark green nearly compact diabase, thin light-coloured well-banded lava, thin green diabase, thin green flaggy beds, and yellowish or greyish arkoses.

The area to the west is formed by Dwyka, and the nearest inlier in that direction is formed of rocks belonging to the Pniel series.

The limestones and cherts are of great interest owing to their remarkable resemblance to those of the Pniel series close at hand, and to those of the Campbell Rand series exposed a few miles away to the north in the Biega Hills.

All the arkoses contain numerous well-worn pebbles of older rocks, seldom of any size, and invariably scattered at random through the beds. The pebbles consist principally of vein quartz, quartzite, granite, aplite, rhyolite, and diabase.

The presence of well-rounded pebbles of rhyolite low down in this formation gives considerable support to the view that the Kuip series is unconformable to the Zoetlief series, and tends to confirm the similar conclusion arrived at from stratigraphical considerations.

## C. The Pniel Series.

As in the area to the north-east, this formation can be separated into two sub-divisions, a lower sedimentary group, composed

principally of quartzite, and an upper volcanic one formed of diabase amygdaloid and breccia.

It was recorded in last year's Report that the formation was traversed by an anticlinal fold extending from Campbell to Hopetown.

To the north of Hopetown a second anticlinal structure was discovered striking north-westwards from Pampoen Pan and crossing the Orange River below its junction with the Vaal. By its means the overlying Black Reef formation is brought up from the level of the river to a point fully 600 feet above the latter.

The Orange River has cut a deep narrow gorge through the anticline, and the basal quartzites have been laid bare from beneath their cover of volcanic rocks. The dip of the strata in the south-west limits of the anticline is in places about 45 degrees.

With the exception of the inliers at Pampoen Pan and the exposures in the gorge of the Orange River to the east, the whole of the north-central portion of Hopetown is formed by the Dwyka series. Between the Leeuwen Berg and Joostenberg there is a belt of ground in which a number of small inliers of diabase crop out through sand-covered Dwyka.

Towards the south-east the base of the formation is being approached, and between Hopetown and Beer Vlei there is a chain of inliers in the Dwyka in which the lower quartzite group plays an important part. Not only are the boundaries of the inliers most irregular, but the dips vary, and it is apparent that the formation is affected by two series of foldings, a gentle set which strike north-eastwards and a more pronounced set which strike north-westwards.

The quartzites appear at irregular intervals from beneath the volcanics, and only rarely form such extensive outcrops such as, for example, on Wit Poort, Wit Punt, and Scorpion's Kraal.

(1) *The Lower or Sedimentary Group.* The quartzites are light-coloured, as seen in the outcrop, but greenish in colour when taken from wells. They are commonly gritty, and sometimes very felspathic, and often contain pebbles of quartz, quartzite, cherty, and slaty rocks, etc. At a few places there are softer sandstones and occasionally some flagstones. On Lange Dam, where they rest directly upon gneissic granite, the beds probably do not exceed 75 feet in thickness, but on Klein Roode Dam they must have at least double that value. This thickness is maintained for some distance to the west, but just beyond Swingel's Pan, where the granite reappears, the quartzites do not exceed about 10 feet in thickness, the lower portions being full of fragments of pink felspar and pebbles of quartz and quartzite.

There is no doubt that the Pniel series has been deposited on an uneven surface of older rocks, and consequently consider-

able variation in thickness of its basal sub-division may be expected. In this case, however, it seems very likely that there is a local unconformity at the top of the quartzites, for first of all certain beds are missing from the latter, which are well developed both to the east and south, and secondly the volcanics which overlie them are not the peculiar breccias by which they are almost invariably succeeded.

A few miles east of Swingel's Pan, on Jantjes Fontein, Scorpion's Kraal and Alleman's Dam, there makes its appearance at the summit of the quartzites a thin group of calcareous quartzites and grits, brown weathering limestones, and dark cherts, succeeded by, and sometimes interbedded with, volcanic rocks, chiefly breccias.

These remarkable rocks, which recall those previously described from the Kuip series, are, as will be inferred from what has been said, absent at the west end of Swingel's Pan, but can be traced southwards round the edge of the high ground north of Beer Vlei, *e.g.*, on Vilet's Kuil, Bidouw's Kuil, Kalk Punt, and Kalk Kraal, and appear again in an inlier at the north end of the T'Kuip Hills.

This inlier shows hard white quartzites with some felspathic and pebbly portions dipping at a high angle to the north, and thus striking almost at right angles to the arkoses and volcanics of the Kuip series seen about 200 yards to the south.

The quartzites are fully 600 feet in thickness here, including a central band of dark blue limestone, and at their upper limit pass into calcareous grits with limestones and black cherts, followed by hard flinty shales, and then by volcanic rocks.

The quartzites are much less felspathic than the Kuip arkoses, but they include the same assemblage of pebbles, *e.g.*, quartz, quartzite, granite, aplite, chert, felsite, and rhyolite, the inclusions being seldom more than a few inches in diameter.

The quartzites are not seen again for a considerable distance, owing to the covering of Dwyka, but apparently curve round and strike in a south-south-easterly direction, the deflection being produced by the anticline traversing the T'Kuip Hills. On the farm Roode Poort the strata make their appearance resting on the granite and having a low dip to the south-west, the thickness being about 150 feet. The limestones are present at the summit of the sedimentary group, and are succeeded by volcanic rocks.

The presence on Roode Poort of the granite, as the basement rock shows that both the Kuip and Zoetlief series disappear in this direction, is confirmation for the existence of a marked unconformity at the base of the Pniel series. At the north end of the T'Kuip Hills the latter probably is in contact with the Kuip series, but the junction is covered by a narrow belt of Dwyka. North of Beer Vlei the rocks nearest to the Pniel quartzites are the rhyolites of the Zoetlief series; further to the north and north-east the underlying rock is granite.

(2) *The Upper or Volcanic Group.* A remarkable feature about this group is the occurrence almost throughout this area of a peculiar volcanic breccia resting almost immediately upon the sedimentary group. This breccia, which was recorded as being present in the gorge of the Orange River near Hopetown,[1] consists of masses, more or less angular or irregular, of a light-coloured felsitic rock set in a greenish diabasic groundmass. Sometimes the matrix is a hard black flinty material, probably of sedimentary origin.

The breccia can be readily recognised in the field, and hence its value in unravelling the structure of the area occupied by the Pniel series.

The breccias, through weathering, give rise to low mounds thickly strewn with blocks of light-coloured lava. They are accompanied by light-coloured compact or vesicular flows, evidently of a less basic nature than the diabases by which they are succeeded.

A prospecting pit sunk in this breccia on Karree Dam shows that the fresh rock consists of fragments of pink felsite set in a dark green matrix, which contains veins and patches of quartz, actinolite, epidote, and a pale brownish garnet.

The breccia is found to be present all over the area between Hopetown and T'Kuip, and has probably a wide extent, for it overlies the quartzites in the anticline on the Orange River south of Mazel's Fontein.

The succeeding volcanics are generally more normal diabases and amygdaloids, well seen, for example, along the Orange River north of Hopetown and again between Karree Dam and Karree Kloof north-west of Strydenburg. There is one horizon of great importance about 150 feet or 200 feet above the summit of the quartzites characterized by the occurrence of green flags, blue limestones, and black cherts like those in the "lower zone." The succession is well seen on Roode Poort south of T'Kuip, and in the chain of low hills that extends northwards into Maritz Dam. The hill north-east of Omdraai's Vlei is an inlier in the Dwyka, and shows the limestones and cherts intercalated between volcanic rocks and dipping at a moderate angle to the west.

This outcrop is of more than usual interest, for both the limestones and the cherts show very fine oolitic structures, and are identical with some of those of the Campbell Rand series.

This little zone is evidently by no means widely distributed, but was discovered again to the north-east on the farms Alleman's Dam and Drooge Dam, where the full succession is seen from the quartzites upwards, the latter having limestones and cherts at their upper limit.

The existence of these two calcareous and cherty zones is thus of very great value in rendering clear the stratigraphy of

[1] Ann. Rept. for 1906, p. 101.

the area, especially as the exposures of this formation are generally in the form of small or more or less isolated inliers in the midst of the Dwyka series.

There is not much to add to previous accounts of this formation regarding the nature of the volcanic rocks. The great bulk of the material consists of green compact or amygdaloidal diabase, in which the ferro-magnesian minerals have been completely chloritized, and the rest of the rock more or less silicified. The silicification has been usually more complete in the case of the lighter coloured, finer grained and presumably less basic types. The alteration has in many cases been so considerable that it is impossible to determine the exact nature of the rock originally.

Porphyritic lavas are rather rare. They were noticed in the angle of the Orange River in the north of Hopetown on the farms Roode Kop and Annex De Hoek (at the Mark's Drift Mine).

Sometimes the volcanic rocks are stained with copper compounds, *e.g.*, Pampoen Pan, where the minerals are found associated with quartz along a line of crush or fracture in the diabase.

## IV. The Black Reef Series.

The Black Reef series appears at intervals between Douglas and Read's Drift, and possesses much the same characters as in the area to the north-east. At the Mark's Drift Mine the basal quartzites crop out along the Orange River and rest upon the Pniel diabase. At Mazel's Fontein the formation reappears and, as already mentioned, owing to the presence of an anticlinal fold, the outcrop is carried to an elevation of about 600 feet above the level of the river.

At the summit of the anticline, on Katlani, the Black Reef is much thinner and more shaly than usual, facts which suggest that the anticline may have been initiated at a time preceding the deposition of the Transvaal system, and that its development continued into the period occupied by the formation of the latter.

On the west side of the anticline there are a number of little patches of Black Reef quartzite dipping at angles of from 20° to 35°, and the beds cross the Orange River from McCowan's Kloof to Paarde Kloof. The diabase and Black Reef form a pretty considerable ridge against which the Dwyka tillite is banked.

The country further down the Orange River is formed in great part by the Dwyka, and the numerous boulders weathered out of the latter, together with the dense growth of thorn trees, chiefly the unpleasant "hakdoorn," render geological exploration difficult. From beneath the thick cover of Dwyka the Black Reef and Campbell Rand series project in a series of

cliffs and ledges, or else appear in the small gorges opening into the Orange River.

The Black Reef series forms conspicuous flat-topped hills along the south side of the river on the farm Blaauw Kop, and the rocks are more shaly here than is usually the case.

The lowest beds are hard white quartzites, which alternate with soft shales of various colours—green, blue, black, whitish, or red—followed by green flags and greenish-black quartzites, which cap the hills.

The uppermost beds and their passage into the Campbell Rand series is seen on Vaal Krantz, and in the gorge of the Orange River on Dopper Fontein and Zand Fontein. At this point they disappear beneath the Dwyka, and are only seen again at the south end of the Doornberg in Prieska.

The thickness of the formation near Blaauw Kop is not capable of exact measurement, but cannot be far from 300 feet.

*Relation of the Black Reef to the Pniel series.*

The unconformity at the base of the Black Reef is only brought out by a careful examination of the junction of the two formations.

At the Mark's Drift Mine, where the exposures can be rather well seen along the Orange River, there is at first sight a perfectly conformable succession. The sequence is as follows:—(1) Amygdaloidal diabase, (2) flow of massive porphyritic lava about 10 feet thick, (3) green diabase from 3 to 5 feet, (4) massive grey quartzites. For quite a considerable distance along the right bank of the river this succession holds good. On the left bank of the river at the mine the copper lode which is being worked occurs in a wide body of compact diabase, which is quite different petrologically to anything in the neighbourhood, and which must therefore be an intrusion in the Pniel volcanics. Immediately across the river are the Black Reef quartzites with no signs of any intrusion, but the reef is marked by a few veins of quartz, which cannot be traced for any distance however.

It is very probable, therefore, that we have here an intrusion which is younger than the Pniel series, but older than the Black Reef quartzites, and that there is a deceptive conformity.

Again, in the western limits of the anticline on Paarde Kloof the two formations possess a similar dip and strike the thickness of the volcanics measured from the top of the Pniel quartzite to the Black Reef along the left bank of the Orange River, being about 500 feet.

On the right bank the volcanics are thinner, and as the Black Reef is traced away from the river it approaches and nearly comes into contact with the Pniel quartzites. Still further north it rests upon a considerable thickness of diabase.

Close to the beacon common to Mazel's Fontein, Floris Fontein, and Katlani, there is, near the base of the quartzites, a layer of greenish conglomerate containing well-rounded pebbles, chiefly of diabase and grey limestone, up to five inches in diameter. The diabase is evidently derived from the underlying Pniel volcanics, but the source of the limestone is not evident.

## V. The Campbell Rand Series.

The limestones and dolomites forming the Kaap Plateau extend as far to the south-west as Dopper Fontein, where this remarkable tableland comes to an abrupt termination.

The escarpment, which has an altitude here of about 3,925 feet above sea-level, now bends to the north-west and continues at this level almost as far as Griqua Town.

The Orange River has cut through this formation just before reaching Read's Drift, and flows for five miles in a deep gorge, bounded by cliffs of dark limestone several hundreds of feet high.

All round about Read's Drift the Pre-Karroo rocks are deeply buried by Dwyka tillite, but at one locality about four miles below the drift the Campbell Rand series reappears along the river for a short distance

The whole of the valley of the Sand River (Lanyon Vale) and the north-eastern portion of Prieska are in all probability underlain by this formation, but the rocks do not project through the Dwyka until we reach the Biega Hills.

The strata consist of the usual brown weathering limestones and dolomites, with occasional beds of flagstone. Chert is common in the upper half of the series, and forms low hills on the plateau south-south-east of Griqua Town. Peculiar dark red chert occurs along with the more common grey or black varieties in the central hill on Biega.

## VI. The Griqua Town Series.

The banded ironstones of the lower division of this formation commence in the bend of the Orange River at Prieska, and extend northwards past Griqua Town, the altitude of the range increasing gradually and continuously through that distance.

The Eastern side of this range, usually known as the Asbestos Mountains or the Griqua Town Hills, is well defined, and at the foot of the low escarpment of ironstones lies the Dwyka, the feature being, therefore, a repetition of the eastern edge of the Kaap Plateau.

Towards Griqua Town the Dwyka is concealed beneath thick deposits of calcareous tufa and gravels, which form a continuation of the peneplain of the Kaap and the junction of the Griqua Town with the Campbell Rand series is entirely hidden.

The low range is gashed in a number of places by narrow,

steep-sided, transverse gorges, often several miles in length, and through these the drainage from the north-west makes its way to the Orange River. On the west of the ridge proper the country becomes more open, while deep red sand covers up the rocks in the valleys.

The dips of the rocks are generally westwards or north-westwards at low angles, but on Brak Fontein and Blaauwbanks Fontein there are sharp anticlinals, which strike nearly north and south.

Occasionally the strata are crossed by gentle folds striking north-west, for example, on the farm Spioen Kop.

The ridges show numerous clefts in more or less straight lines, which are due in most cases to the presence of dykes of diabase. In several cases no igneous rock could be discovered, and the features may perhaps be due to the weathering of beds along lines of crush. The walls of the ravines in the Griqua Town series are generally precipitous, and show numerous little caves. It is usually possible to make an ascent by the cleft determined by a dyke or line of crush.

The strata are the usual brown, red, or black banded ironstones and jaspers, of which a description has already been given by Mr. Rogers.[1] Extremely tough dark blue and brown banded rocks, rich in crocidolite, occur at a number of points, notably on Elands Fontein and Roode Pan. Fibrous crocidolite (asbestos) is being mined on the first-mentioned farm and on Krans Hoek; the mineral is, however, widely distributed.

The various oxidation and silicification products of the crocidolite, colourless, blue, or yellow-brown, are frequently found, the last named being the most abundant variety.

## VII. The Dwyka Series.

As in the area to the north-west, this formation can be separated into a lower division characterized by boulder-beds, and an upper division composed of dark shales, which are separated from those of the Ecca by means of the "White Band." Along the south-eastern edge of the Dwyka belt the boulder-beds are thin, but along the Vaal-Orange River valley the deposit attains a considerable thickness. This feature is a repetition of that seen towards the north-east.

*Surface upon which the Formation Rests.* Everywhere the Dwyka rests unconformably upon an undulating or very uneven floor of older rocks. The rocks forming the great ridge on the right bank of the Orange River near Douglas pass below the Dwyka in the north of Hopetown, and no exposures of pre-Karroo rocks appear again until the Brak River is crossed. Be-

[1] Ann. Report for 1905, p. 156 and onwards.

tween Hopetown and Omdraai's Vlei the older rocks appear at intervals through the Dwyka, and the outcrops evidently indicate a partially-buried ridge.

Towards the south-east the level of the base of the Karroo formation falls, as has been clearly proved, by the deep borehole at De Aar. In the north of Hopetown and in Prieska is found the continuation of the pre-Dwyka valley of the Harts-Vaal River, its north-western limit being the Kaap Plateau and Griqua Town Hills, with a tributary from the north now occupied by the Sand River. Variations in altitude of the base of the Dwyka, amounting at times to over 1,000 feet, are evident from a study of the Orange River sections.

The Dwyka is found resting against the face of the Griqua Town Hills, and no doubt at one time overlay the whole of the Hay division. Some of the north and south valleys in which the rocks are concealed by red sand, *e.g.*, Niekerk's Hope, are very probably of pre-Dwyka age, and have been re-excavated since.

An idea of the nature of the surface on which the Dwyka was deposited can be gathered from an examination of the Orange River valley near Blaauw Kop. Here we find numerous ledges of rock (Black Reef and Campbell Rand formations) projecting from the mantle of glacial deposit, and indicating a former landscape of most diversified aspect. In pre-Dwyka times the ground must have risen in a series of steps for over a thousand feet, and must have been of an extremely rugged nature. The old escarpments frequently show glacial striations wherever the overlying deposit has been removed by denudation.

*Direction of Glaciation.* Striated surfaces occur at a number of points, generally along the Orange River. In most of these the direction of glaciation is from the north-east to the south-west, but there are several localities where the divergence from this direction is considerable. In the following table the bearings are in each case measured from the true meridian:—

| | |
|---|---|
| Naauwtes Fontein (Hopetown) ... ... | S. 53° E. |
| Brand Fontein (Hopetown) ... ... ... | S. 63° E. |
| Slyp Steen, No. 2 (Hopetown) ... ... | S. 80° W. |
| Kameel Drift (Hopetown) ... ... ... | S. 50° W. |
| De Kalk (Hopetown) ... ... ... ... ... | S. 35°-50° W. |
| Mark's Drift (Hopetown) ... ... ... | S. 20°-35° W. |
| Blaauw Kop (Hopetown) ... ... ... ... | S. 30° W. |
| Mazels Fontein and Vaal Krantz (Herbert) ... ... ... ... ... ... ... | S. 40° W. |
| Read's Drift (S.W. of), (Hay) ... ... | S. 35° W. |
| Karree Dam (Hopetown) ... ... ... ... | S. 28° E. |
| Vilet's Kuil (Hopetown) ... ... ... ... | S. 25° E. |
| Wonderdraai (Hopetown) ... ... ... ... | S. 10° E. |
| T'Kuip Hils (north), (Prieska) ... ... | S. 30°-45° W. |
| T'Kuip Hills (south), (Prieska) ... ... | S. 20° W. |
| Ruitjes Vlakte (Britstown) ... ... ... | S. 5° W. |

The Pniel diabase retains the striations very well along the Orange River, but in the central portions of Hopetown, in spite of the numerous exposures of that rock as inliers in the Dwyka, only one spot was found where the groovings were still apparent. This was on Karree Dam, where the surface had been exposed in the overflow from a dam. At Mazels Fontein there are some fine surfaces in a stream bed along the road north-west of the homestead. The rocks consist of the limestones and flagstones of the Campbell Rand series, and whereas the striations are well preserved on the latter, only the wider groovings are retained by the limestones. This is due to the rapid weathering of the limestone upon exposure; even calcareous patches in the flagstones behave in the same way. Limestone boulders in the Dwyka are as a rule rough, and never show any striations. If, however, they are dug out of the rock, then the protected surfaces are found to be polished and striated.

The Griqua Town ironstones do not form suitable material for preserving the effects of glaciation. The rocks are well bedded, and generally dip towards the west, *e.g.*, more or less in the direction of the glacial movement. At the junction with the Dwyka, the ironstones have been tilted up, great blocks have been torn out bodily, and striations cannot be clearly made out. At Blaauwbanks Fontein, however, at the great bend in the Orange River, the Griqua Town beds form a sharp anticline now emerging from its cover of Dwyka. Just where the road to Prieska crosses from the Dwyka on to the Griqua Town beds, the latter present a nearly vertical finely striated face, the scorings passing obliquely upwards, and being directed towards the south-west. The outcrops of rhyolite at Vilet's Kuil exhibit all the features typical of *roches moutonnées*, and in spite of the prolonged weathering to which they must have been exposed, nevertheless still retain in a few places beautifully glaciated surfaces.[1]

The granite is not a suitable material for the preservation of striations, but a small outcrop on Ruitjes Vlakte showed some well-marked groovings.

There is a peculiar characteristic of a few of the glaciated outcrops which is worthy of note. Instead of the knobs being smoothed and evenly curved like those so well seen along the Vaal River, the exposures show jagged surfaces, with the corners and edges ground down and polished. This is well seen in the rhyolite inlier on Wonder Draai, near Strydenburg, and in the exposure of diabase on Karree Dam. Apparently the ice sheet was unable to grind down these knobs of rock sufficiently so as to form smooth curved surfaces; but instead, tore out blocks of material and rounded off the rugged surface which resulted. May it not, therefore, be that the ice sheet exercised a less erosive action in central Hopetown than in the area to the north-

[1] Ann. Report for 1899, pp. 96-7.

east? There can be no doubt that still further to the south and south-east, in the area hidden by younger Karroo deposits, the Dwyka boulder-bed was deposited in water, probably through the agency of floating ice. At some intermediate point, therefore, the ice-sheet must have ceased to rest upon and grind down the rocks forming the Karroo floor.

*Transport of Boulders.* Many of the boulders in the "boulder-beds" are of rocks which are found *in situ* to the north-east, thus conforming the evidence afforded by the glacial striæ.

Inclusions of the rhyolites of Klokfontein and the Riet River are found along the Orange River from Naauwtes Fontein to Mark's Drift and Dopper Fontein, and they have also been noticed round about Karree Dam, Kalk Punt, etc., north-west of Strydenburg. Boulders of quartzite and diabase breccia are abundant in the Dwyka along a belt extending from near Hopetown to Beer Vlei, in which the Pniel quartzites and volcanics appear.

Masses of Campbell Rand limestone form an essential constituent of the Dwyka of the Sand River area and around Read's Drift, Dopper Fontein, etc. The blocks of limestone are sometimes many feet across, but tend to break up on exposure to the weather, and the slopes of Dwyka are strewn with little fragments of the brown-weathered limestone. The rock, derived as it is from the lower half of the Campbell Rand formation, is fairly free from chert, and is thus distinguishable from the inclusions from the Dolomite of the Transvaal. Boulders of the Griqua Town jasper are only found within a short distance of the foot of the Griqua Town Hills, for example, on Krans Hoek, Spioen Kop, and Blaauwbanks Fontein. On the latter farm the inclusions first appear about half a mile east of the nearest exposure of Griqua Town beds. Immediately west of the anticline of jaspers, the Dwyka is crammed with great blocks of the latter material, some of them angular or jagged, and evidently torn *en masse* from the ridge, while others are rounded and well striated.

Generally speaking, boulders of diabase and amygdaloid are the predominant constituent of the Dwyka, which is not surprising, considering the huge area to the north-east which is composed of these rocks. Quartz-porphyry and granite are not uncommon, while blocks of a red variety of granite, probably from the Central Transvaal were also observed, notably at Sand Drift and Blaauwbanks Fontein.

*The Boulder-beds.* Along the south-eastern side of the Dwyka belt the boulder-bed is generally thin, and often intensely hard, and is usually succeeded directly by bluish and greenish shales. This is the case at Hopetown, De Kalk, Drie Kopjes, Geluks Poort, and Gemsbok Vlakte, to mention a few instances.

Further north, where the Dwyka fills up a great depression, the deposits are much thicker, probably in places over 400 feet,

and consist of alternations of conglomerate, "gravel Dwyka," and boulder shale, with occasional shaly and calcareous layers. There are numerous fine sections of this phase of the Dwyka along the Orange River, between Read's Drift and Prieska, especially at bends where the river has cut laterally into a gravel-capped terrace, and laid bare a face of Dwyka from 250 to 300 feet in height, for example, at the Sand Drift Mine. In this last-mentioned locality the upper portion of the cliff is formed of a huge thickness of intensely hard gravelly Dwyka, underlain by softer bluish tillite.

The maximum thickness of the deposit is difficult to estimate, owing to the considerable variation in altitude of the floor of older rocks. The Dwyka is the formation exposed in the valley of the Sand River from Read's Drift for a considerable distance northwards. The Kaap terminates in an escarpment on Wit Berg and Naras, and the rock building it up here is the Dwyka, with a thick capping of tufa and gravels. The Campbell Rand beds and the Dwyka have equally been cut to a flat, with an altitude of about 800 feet above the Orange River at Read's Drift. The Sand River valley represents, therefore, a great depression, which has been filled in with Dwyka, and the thickness of the latter may therefore have exceeded 800 feet.

The boulder-beds reproduce in their dips the undulations of the floor upon which they rest, and at several places the inclination of the beds is over 30°, for example, close to the Orange River on Blaauw Kop. At Blaauwbanks Fontein, however, the bedding of the Dwyka remains horizontal, in spite of the fact that the Griqua Town beds form an inlier rising in a most abrupt manner to an altitude of about 400 feet above the level of the river.

*The Upper Shales and White Band.* Dark-coloured shales, succeeded by the White Band, overlie the boulder-beds and crop out in a narrow belt, which extends from Hopetown past Limiet's Kop and Strydenburg, and which passes to the south of Beer Vlei. A thick sheet of dolerite is invariably intruded either immediately below, in, or above the white band, and the upper limit of the Dwyka formation is in consequence generally defined by a line of low dolerite hills. Dolerite-capped outliers of shale lie to the north-west on Joostenberg, Leeuwberg, Kaffir's Kop, Geluck's Poort, Drie Kopjes, Elands Nek, and Maideberg, a little to the north-west of Beer Vlei.

In the dolerite outlier on Uitdraai, a little to the east of Prieska, the intrusion occurs at the junction of the shale and boulder-bed.

The shales are the usual bluish or greenish varieties, which are sometimes of a rather flaggy nature. Whitish sandstones are not represented. Calcareous nodules sometimes occur, more commonly huge brown ferruginous concretions, *e.g.*, Perskie Dam. The shales have fucoid-like markings and casts of worm burrows. The carbonaceous white weathering shales constitu-

ting the White Band are well seen at a number of points from Hopetown in a south-westerly direction, for example, on the Commonage, Ganna Hoek, Limiets Kop Fontein, Perskie Dam, Plat Kuil, Vlak Fontein, Taaibosch Draai, etc. On Limiets Kop Fontein several wells show very finely the passage from the snow-white weathered shale into the unaltered black carbonaceous material. The zone is probably about 50 feet in thickness.

The shales of the white band are soft and flaky and very fine-grained. Along with the snow-white material are pink and red varieties, due to the staining of the shales by oxides of iron from the decomposition of iron sulphide. In a well on Middel Dam the black shales are full of pyrites and marcasite, and yield on decomposition ochre and gypsum. Heavy ferruginous layers and ocherous concretions are numerous in the white shale.

*Fossils.* Only a few fossils have been obtained from this formation within this area.

At Wonderdraai, near Strydenburg, there rest against the rhyolite inlier described earlier in this Report a few feet of intensely hard conglomerate or breccia, in which fragments of the rhyolite predominate. The groundmass forms only a small proportion of the rock, and is a hard black flinty shale, and in this material, wedged in between boulders of rhyolite, were found some fragments of an uncrushed but carbonised plant stem and a portion of a frond of *Gangamopteris.* The fossil thus occurs within a few feet of the base of the Karroo system of rocks.

At Elandsdraai, close to Orange River Station, the core from a bore-hole in the Dwyka shales yielded two fossils. One of these is a small crustacean, not yet described; the other is a portion of a stem which has been identified by Prof. Seward with *Lepidodendron australe* (Mc'Coy),[1] a form occurring in the Lower Carboniferous and Upper Devonian of Australia. These fossils were obtained by Mr. F. B. Parkinson, A.R.C.S., and presented by him to the South African Museum, Cape Town.

## VIII. The Ecca Series.

Succeeding the rocks of the White Band is a considerable thickness of dark bluish or greenish shales, with occasional calcareous concretions. These beds can to a certain extent be subdivided according to lithological differences. At the base come several hundred feet of hard creamy coloured splintery shales, with a tinge of green, and which are not so white and flaky as those of the White Band, nor do they contain pink or reddish bands. Limestone concretions are not very common, and are usually light in colour, with a crystalline structure. This zone

---

[1] Geological Magazine, p. 484, 1907.

is well developed to the east and south-east of Strydenburg, and to the south-east of Beer Vlei.

It is succeeded by soft dark blue or blue-green crumbly shales, with abundant concretions of dark red-brown weathering limestone, full of little veins of greenish shale, and often exhibiting cone-in-cone structure. These shales form flats between Strydenburg and Potfontein, *e.g.*, De Put, Rhenoster Valley, Diedericks Put, etc., and frequently build up dolerite crowned hills, *e.g.*, Jackals Toren, Strykuil Kop, Tigerberg, De Put, etc.

The uppermost beds of the Ecca are hard greenish and bluish shales and flagstones, in which calcareous concretions are not common. These flaggy beds build up the Rhenoster Berg near Behr's Hoek, and appear along the railway between De Aar and Potfontein. Near the summit of the Rhenoster Berg whitish sandstones in thin beds make their appearance, alternating with crumbly sandstones and mudstones, and the pile of sediments is capped by a horizontal sheet of dolerite. This arenaceous horizon appears in the ranges east of the railway in the direction of Philipstown and Hanover, and seems therefore to be persistent. As this is the first horizon at which sandstones make their appearance in the Karroo beds, it will probably be of much assistance in the work of dividing this formation into zones. It is noteworthy that a similar section of the Ecca has been recorded in Calvinia,[1] and that the base of the Beaufort series has there been taken at the horizon where massive yellow weathering sandstones succeed dark bluish flaggy shales.

A few plant stems were found in one of the sandstones of the Rhenoster Berg, also some pieces of silicified wood, but the flaggy shales of the Ecca are often crowded with indeterminate fucoid-like impressions.

At De Aar Station a borehole, 1,630 feet in depth, was put down by the Railway Department,[2] penetrating Ecca shales and dolerite; as far as can be judged from the samples of core, the Dwyka formation was not reached, and this borehole is therefore of immense value in indicating the fall in level of the Karoo floor towards the south. The altitude of De Aar is 4,080 feet above sea-level, and the bottom of the borehole stands thus at 2,450 feet.

The section of the borehole shows a series of bluish shales, which carry in their lower portion calcareous concretions, and which are split up by sheets of dolerite, namely, 52-139 feet, 432-695 feet, 1,020-1,080 feet, and 1,605-1,630 feet. These dolerite sheets include thin layers of metamorphosed shale and mudstone.

The thickness of Ecca beds at De Aar is thus 1,300 feet at the least, but the total thickness of the formation, as indicated by the sections in the Rhenoster Berg, will exceed this value somewhat.

[1] Annual Report Geol. Commn for 1903, p. 33.
[2] Report on Water Boring on the Cape Government Railways for 1903, p. 4.

## IX. The Intrusive Rocks.

*A. Pre-Karroo Intrusions.* At the Mark's Drift mine, as mentioned earlier in this Report (p. 175), a metalliferous lode occurs in a mass of diabase, which is very probably intrusive in the Pniel volcanics. In thin section (1890) the diabase is found to contain large pseudomorphs in serpentine, probably after a pyroxene; pseudomorphs in carbonates after felspar, and shows ilmenite altered to leucoxene. The groundmass consists of micropegmatite.

The lode stuff is composed of quartz and calcite, with chalcopyrite, galena, and blende.

At Blaauw Kop, adjoining the Orange River, is a diabase dyke, about 50 feet wide, cutting through the Black Reef series. In the neighbourhood of the river it is overlapped by the Dwyka, but reappears further north, where it is intrusive in the limestones of the Kaap.

The dyke is remarkable for the number of narrow veins of quartz and calcite which traverse it. They are regular, and run more or less parallel to the walls of the dyke. The rock itself shows a banded structure, but has been so altered that its original nature cannot be made out under the microscope. The material appears worthy of further examination.

Another dyke is found crossing the Orange River a little to the north-west of Blaauw Kop. It is (1892) a fresh rock, with a sub-ophitic structure, and shows nearly colourless augite frequently twinned, biotite, magnetite, and a little hornblende fringing the augite. The groundmass is of felspar and quartz, forming micropegmatite.

At Dopper Fontein there is an interesting basic dyke, which can be traced up the face of the escarpment almost to the summit of the plateau. Then it spreads out, and terminates in the limestones and shales, the latter being tilted away from the dyke and greatly contorted and metamorphosed. Both the latter and the dyke at its apex are veined by quartz. Two other dykes are found a little to the north-east, and are accompanied by quartz carrying a small amount of copper minerals.

On T'Kuip East a diorite dyke cuts through the granite in a south-easterly direction. The rock has weathered at a greater rate than the granite, and the dyke produces a distinct road-like feature, flanked by odd-looking knobs of granite.

The thin section (1911) shows idiomorphic colourless augite, serpentine pseudomorphs probably after enstatite, brown hornblende and biotite usually intergrown, magnetite and apatite. The remainder of the slide is composed of slightly clouded plagioclase felspar, the structure of the rock being holocrystalline.

Diabase dykes are frequent in the T'Kuip granite. Most of these are fine-grained, but several are highly porphyritic at their

contacts with the granite, the felspar phenocrysts being occasionally over one inch in length.

*B. Karroo Dolerites.* In this area dykes of dolerite appear to be rather uncommon, and the intrusions are nearly all in the form of more or less horizontal sheets, penetrating the Dwyka and Ecca shales. Hence the numerous dolerite-capped hills, which are so well represented in the southern portion of this area, *e.g.*, Leeuwen Berg, Joostenberg, Drie Kopjes, Elandsberg, Limiets Kop, Strydkuil Kop, De Put, Rhenoster Berg, etc.

The northern portion of this area is practically devoid of dolerite, and the only sheet of any importance is that on Uitdraai, adjoining the Orange River east of Prieska.

The dolerite sheets have, as in the area to the north-east, the same tendency to variation in altitude, in accordance with the undulations of the floor of the Karroo beds. This is well marked between Hopetown and Omdraai's Vlei.

Generally the lowest sheet has been intruded in or close to the horizon of the "White Band," while other sheets penetrate the shales of the Ecca. The deep borehole at De Aar proves the existence of several of these sheets, one below the other.

The dolerite is usually the typical ophitic rock, with or without olivine. Some of the intrusions possess a sub-ophitic structure, however.

The intrusions have in many places converted the shales into porcellanite and lydianite, and calcareous nodules into impure crystalline limestones.

## X. The Diamondiferous and Allied Pipes.

Several occurrences of ultra-basic breccia or kimberlite, commonly known as "blue-ground," have been found in this area, and of these one at least is diamond-bearing.

(1) At Sand Drift, in the Hay Division, not far from Prieska, the Orange River flows at the base of a cliff about 275 feet in height, formed of Dwyka boulder beds, capped by tufa and river gravels. Diagonally up the face of cliff runs the outcrop of a vertical fissure from 4 to 8 feet in width, filled with kimberlite, and striking nearly north-east. This fissure can be traced for some distance north-eastwards, until it comes into contact with a sill of dolerite, and is broken into narrow irregular veins and stringers. On the line of fissure is a small circular pipe, about 50 feet in diameter, which is later in age than the fissure. There appear to be three phases of intrusion at Sand Drift. First a sheet of hard fine-grained micaceous kimberlite parallel to and overlying the dolerite sill. Secondly a vertical fissure filled with soft yellow weathering kimberlite, cutting transversely through the earlier intrusion. Thirdly the pipe filled with pale bluish kimberlite. Fragments of black (Dwyka) shale and tillite are most abundant in the pipe, whereas in the fissure they are but poorly represented, and are accompanied by boulders of

peridotite. Mr. Robert Scott, late manager of the mine, informed me that the diamonds obtained from the fissure were darker, more irregular in shape, and of poorer quality than those from the pipe.

(2) In the extreme north-eastern corner of Viool Kraal (Britstown), in the midst of dolerite hills, is a small pipe, which is interesting for the number of small inclusions of granite and gneiss in the kimberlite. The pipe penetrates dolerite and the "white-band" of the Dwyka series.

Another small pipe exists in the north-western corner of the farm, in a small kloof leading to Karree Hoek.

A boulder from this pipe proves under the microscope (1893) to be a gabbro of rather uncommon type. The rock is composed of plagioclase felspar approaching labradorite in composition, accompanied by a small amount of more acid felspar and a little quartz. Augite is present, altered generally to diallage, and intergrown with or surrounded by hornblende. The latter has a pleochroism from yellow to dark green, and occurs in interlocking areas with a tendency to idiomorphic outline. Numerous little hornblendes are included in the felspars. The rock shows an approach in structural character to the granulitic gabbros.

(3) Small pipes occur on Uitkyk and Barends Fontein, in Britstown, while the contacts of kimberlite and shale have been exposed in wells on T'Orroo and Middel Dam, in Hopetown. In none of these occurrences, however, has any attempt been made to prove either the size of the pipes (or fissures), or the existence of diamonds in the kimberlite.

(4) On the farm Rietfontein (incorrectly known as De Put) along the western border of the Philipstown division are some peculiar occurrences, which probably are to be connected with the kimberlite intrusions. On the western boundary of the farm there rise from a flat of shales three little hills, united at their base and crowned with dolerite. On the slopes of each of the three hills are boulders of dolerite and portions of hard shale, more or less tilted and shattered. Excavations show a peculiar greenish blue breccia, soft and somewhat clayey, and full of fragments of soft and hard shale, limestone (nodules), and dolerite. The latter is in more or less angular blocks, up to three feet across. The shale fragments have the angles rounded off, and show smooth greasy faces, sometimes well striated. No foreign boulders were noticed in the breccia. The material thus recalls the "floating-reef" of the Bultfontein and Kamfersdam mines. The dolerite at the summit of the three little hills probably represents the remnants of an intrusive sheet, such as is seen in a kopje a short distance to the south, but the material has evidently been somewhat disturbed.

Pieces of ilmenite were found in the breccia, while ilmenite and garnet were picked up on the shale flat at the foot of the hills. Hard micaceous kimberlite is exposed in small pits a few hundred yards to the north.

The occurrence is probably an embryonic pipe, whose boundaries coincide more or less with those of the fractured area. The disturbance has not been very great; much of the material is almost *in situ*, while the remainder has been brecciated, and the fragments polished by attrition, without very much vertical movement. It seems most likely that denudation has just laid bare the apex of the volcano, and that further down in the pipe the intrusive kimberlite will be found.

## XI. THE RECENT AND SUPERFICIAL DEPOSITS.

Frequently over wide areas the formations are concealed by soil, sand, or calcareous tufa, and to a lesser degree by river gravels.

In the area occupied by the Ecca shales wide flats extend between the dolerite-crowned hills. These flats are formed of light drab-coloured soil, more or less clayey in character, supporting a scanty growth of small Karroo bushes. After every rain, a thin layer of silt is spread over the surfaces of these flats, and the drainage either makes its way into ill-defined stream courses or gravitates towards a pan.

*Red Sand* is abundant in the central portion of Hopetown, extending eastwards almost to the Orange River. Usually it supports a growth of the little bush *Rhigozum trichotomum* (Burchell) commonly known as Driedoorn, but in the neighbourhood of the Leeuwen Berg, and again at the junction of the Vaal and Orange Rivers grass is abundant. In the south-east, red sand is not very common, but a belt of it extends from Hopetown past the eastern side of Elandsberg. The sand is composed of sub-angular or nearly rounded grains of quartz, coated with iron oxide.

In the valleys west of the Asbestos Mountains there is much deep red sand. The material is carried down in the rainy season to the Orange River, and hence the patches of sand country in the neighbourhood of Sand Drift and Muis Hoek.

*Calcareous tufa* is abundant, especially in the valley of the Orange River below its junction with the Vaal River. It commonly overlies the Dwyka boulder-beds in the north-west of Hopetown and east of Prieska, and the calcareous matter has doubtless been derived in great part from the underlying formation. Tufa conceals the rocks at the base of the escarpment of the Kaap, and is found in quantity on the plateau itself.

*Alluvial terraces.* The most interesting feature in this area is the existence at various altitudes of alluvial terraces, which, by their presence, indicate considerable modification of the original drainage system.

The oldest and most important of these is the Kaap Plateau, the post-Karroo origin of the feature having been suspected for some time, although until now no definite proof has been forthcoming. The nature of this plateau has been briefly described by Mr. Rogers[1]; to his account must be added a note on the southern extremity of the area in question. It has already been remarked that in the Sand River Valley both the Campbell Rand and Dwyka series have been cut perfectly flat and covered with a great thickness of tufa and gravels. The gravels consist principally of brown and black banded jaspers, red jaspers, and grey or black cherts, the pebbles being abundant in the lower portion of the tufa. The fragments are commonly flattish owing of the fissile nature of the material, but their corners and edges are well rounded, while the cherts are well worn. They sometimes exceed six inches in length.

These pebbles have been derived principally from the Griqua Town Hills, about 12 miles to the north-west, and now separated from the plateau by the valley of the Sand River.

Similar gravels are found along the edge of the escarpment at Floris Fontein, and from thence to Campbell. At Boetsap the surface of the plateau is, in the same way as in the Sand River Valley, continued from the Campbell Rand on to the Dwyka series.

The Kaap Plateau is, therefore, a peneplain with, in the southern part, a gentle slope towards the east, the altitude of the present escarpment being almost exactly 4,000 feet over the distance of 170 miles from Vryburg to Read's Drift. A few minor irregularities of the surface have been developed through the existence of the very resistant cherts of the Campbell Rand series. At Takwenen,[2] near Vryburg, however, Mr. Rogers has noticed that the Black Reef and volcanic beds have been cut flat equally with the surrounding limestones.

How far this peneplain continued eastwards is not clear; over a wide area in that direction the country is at a lower level than the 4,000 foot contour owing to the erosion performed by the Orange, Vaal, and Hart's Rivers and their tributaries. The greater portion of this tract is formed of shale flats and dolerite hills, the latter usually attaining an altitude of from 4,000-4,300 feet above sea-level.

It is noteworthy that gravels containing brown jasper pebbles occur south of the Orange River near Blaauw Kop, and that fragments of brown jasper, crocidolite, green quartzite, agate, etc., are picked up many miles to the south-east, either of the Griqua Town Hills or of the Doornberg. The jasper fragments have been found on Jackal's Post, Kain's Vlakte, and Rhenoster Valley along the Philipstown border at about the 3,800 foot contour, and even at Potfontein Station at over 3,900 feet.

---

[1] Ann. Report Geol. Comm. for 1906, pp. 22, 61.
[2] Ann. Rep. Geol. Comm. for 1906, p. 23.

These jaspers are always in small fragments, but further north, in a lower terrace (about 3,500 to 3,600 feet), they are more numerous and larger, *e.g.*, Hopetown, Klip Fontein, Probeer Fontein, De Kalk, Rittel Mago, Blaauw Kop, etc.

It is evident that since the formation of the peneplain of the Kaap the Orange River has cut its gorge to a depth of nearly 800 feet below the level of the plateau. It is clear also that the drainage system at this early period was very different from that of the present day. For example, there is evidence to show that the Harts River came into existence subsequently, and it is very probable that both the Vaal and Orange Rivers had very different courses to those which they now possess.

The second terrace is found along the Orange River at an altitude of from 150 to 400 feet above the stream-level, approximately at the 3,600 foot contour. It is well developed in the northern portion of Hopetown.

This terrace commences at Hopetown, where it is a shelf cut in Dwyka and covered with a layer of gravels from 5 to 10 feet thick, capped by tufa; the deposit is here about 30 feet in thickness, and occurs at from 140 to 200 feet above the river, the terrace having a slight rise to the south.

The pebbles are quite different to those found along the Vaal River, and include quartzite, lydianite, and other indurated sedimentary materials, diabase, dolerite, and of more interest than any of the others, amygdaloidal basalt from the Stormberg beds of Basutoland and the Drakensberg.

Further downstream the shelf is cut both in Dwyka and in Pniel diabase and quartzite, but the river flows in a gorge of ever increasing depth, while the terrace maintains a nearly constant altitude.

On Slypsteen, Kameel Drift, Klip Fontein to Rittel Mago, the terrace is beautifully seen, forming an escarpment following the winding of the river at a distance of several miles. Pebbles of lydiamite and occasionally of brown jasper are abundant.

Just beyond Rittel Mago this terrace slopes down to another at a lower level, but west of Pampoen Pan the escarpment is repeated for a number of miles, *e.g.*, Uitluchtige Pan, Welgevonden, Vraai Plaats, and Kwartels Pan. The terrace at one time extended northwards to the foot of the Kaap, for it is still well marked around Dopper Fontein and south-east of Read's Drift, while outliers exist on Roode Kop, Paarde Kloof, and Blaauw Kop.

The diabase, Black Reef quartzites, Campbell Rand limestones, and the Dwyka tillite are cut to a flat, and into this peneplain the Orange River has sawn its channel, and now flows for a number of miles in a deep gorge, the width of the excavation varying according to the nature of the material it traverses.

It is remarkable to find on the summit of Blaauw Kop, which

is south of the river, gravels in which pebbles of brown jasper predominate.

Lower terraces are found along the Orange River, a most important one being about 3,400 feet above sea-level. It is well seen on De Kalk, Blaauw Fontein, Probeer Fontein, Mark's Drift, and Roode Kop, and again on the north bank of the Vaal River between Douglas and Mazel's Fontein.

Remains of terraces are found at intervals along the Orange River below Read's Drift. The shelves are cut in the Dwyka, and at the bends in the river are many fine sections showing the tillite capped with gravels and tufa, *e.g.*, Kalk Krantz, O. 376 C, Sand Drift, Uitdraai, etc. The altitude is commonly from 250-300 feet above the river. Pebbles of jasper predominate in these gravels, and on the south side of the Orange River diminish in size the further away from the river the deposits are traced.

A high level terrace no doubt extended along the area drained by the Brak River, for this tract of country has very little variation in altitude. The formations consist of the Dwyka resting upon pre-Karroo rocks, and subsequent denudation has tended to remove the covering of softer material and reveal the undulating surface of pre-Karroo sediments and volcanics.

Gravels are, however, found at a number of points along the tributaries of the Brak River, *e.g.*, Walthoorn's Kraal, Knapdaar (near Beer Vlei). The pebbles consist of lydianite and dolerite with quartzites (Karroo sandstones indurated by dolerite intrusions).

Diamonds have been found at various localities in the northern half of Hopetown; as a matter of fact, the first diamond discovered in South Africa was picked up on the farm De Kalk.

It is very probable that the gravels contain many diamonds, but curiously enough along the Orange River, with the exception of a few trifling patches, all the gravels are cemented by calcareous material, and converted into compact conglomerate.

## XII. On Pans.

This area is characterized by the presence of numerous pans, which are generally more or less confined to the tracts occupied by the Karroo beds.

In a few cases, pans have been determined by the removal of the Dwyka tillite from basin-shaped hollows in the pre-Karroo rocks. A fine example of this is Swingel's Pan, due north of Beer Vlei. The pan itself is not large, and is surrounded on three sides by ridges of Pniel quartzites and diabases. On the extreme east the slope of the ground is gradual, and the formation consists of the Dwyka, through which project hummocks of diabase. The catchment area is aproximately 35 square miles.

Pans are numerous in the Dwyka covered northern portion of Hopetown. Sometimes they are shallow depressions in one of the old river terraces, *e.g.*, Blaauw Fontein and Blaauw Kop, at other times they are deeply sunk beneath the level of the surrounding country.

Such examples are Krantz Pan, Zout Pans Fontein, Zout Pan (Prieska), Valsch Pan, Vogelstruis Pan (near Leeuwberg), and Roode Pan (near Blaauw Kop). An important feature about several of these pans is that their north-western boundaries are abrupt escarpments capped with a thick deposit of calcareous tufa. Each terrace, as it can be called, becomes less marked as it is followed round the pan, and on the south-east the slope towards the depression is generally a gradual one. This precipitous feature on the north-west side of the pan is especially well marked in the cases of Krantz Pan, Vogelstruis Pan, and Roode Pan. The origin of these escarpments, which in some cases rise as much as 150 feet above the bottom of the pans, is apparently connected with the prevailing winds which blow from the north and north-west. The hard tufaceous deposit protects the Dwyka shales and tillite from erosion, but on the slopes of the escarpment the sedimentary material suffers rapid disintegration, and is carried to the opposite end of the pan by the action of the wind.

There is in consequence an accumulation of sand around the south-eastern edge of the pan, for example, in Dik Pan and Krantz Pan, while in the pan at Brakkies the sand forms small dunes.

A peculiarity to which attention has been called in last year's Report (p. 126) is the way in which the red colour is removed from sand which has been blown into the pans. This is well seen in the Roode Pan near Blaauw Kop; there is a gradual fading of the red tint of the floor across the pan from north to south, and on the latter side the wind-borne material is of very pale colour and forms a small dune.

There are quite a number of large pans located upon Dwyka or Ecca shales, for example, to the south-west of Strydenburg and again in the Government's Pan between that village and Paauwpan Station.

The latter is an elongated pan, averaging two miles across, with a length of about 16 miles; towards the south-west it widens out, becomes ill-defined, and merges into wide flats covered with a film of hardened clay.

The large pan at Strydenburg occurs adjacent to a sill of dolerite dipping in below the pan itself. The presence of this intrusion has doubtless been the determining factor in the formation of the depression.

Generally, pans excavated in Dwyka tillite yield brack or salt water, for example, the pan on Zout Pan Put (near Hopetown), Zout Pans Fontein, Zout Pan (Prieska), Blaauw Kop, Drie Hoek's Pan, Brak Pan (near Strydenburg), etc. In some of

the pans rain water will stand for a considerable period without becoming brack, but upon digging in the pan, salt water is obtained, *e.g.*, Dik Pan, Krantz Pan. This is due to the clayey and impermeable nature of the surface layers of the floor. Many of the pans, especially those situated upon Ecca beds, yield fresh water.

The Dwyka tillite is the chief source of the salt, for a large number of wells in that formation yield undrinkable water.

Through the gravitation of the sub-surface water towards depressions the saline material is leached out of the rock and concentrated in these hollows. This explains why the water in the pans is so frequently salt.

The wells along the Beer Vlei yield very bad water, a matter capable of ready explanation when it is noted that rocks of pre-Karroo age form hills to the north-east and south-west, and that the drainage from a wide area gravitates into this depression and escapes along a narrow channel at the western end of the vlei, where it is very probable that the Karroo floor is not at any great depth below the surface.

The Brak River and its tributaries yield water of fair quality as far down nearly as the T'Kuip Hills. In the lower part of its course the water is usually only drinkable within a certain period after rains, or in certain spots in its channel. For some distance above its junction with the Orange River the water is undrinkable.

The lower reaches of the Brak River being entirely in the Dwyka tillite area, the source of the saline matter is clearly the formation which the river traverses.

# INDEX.

A.



B.



C.



D.



E.



F.



G.

Q.



R.



S.



T.



U.



V.



W.



Z.

# CAPE OF GOOD HOPE.

## DEPARTMENT OF AGRICULTURE.

# THIRTEENTH
# ANNUAL REPORT
OF THE
# GEOLOGICAL COMMISSION.

1908.

*Presented to both Houses of Parliament by Command of His Excellency the Governor,*
*1909.*

CAPE TOWN:
CAPE TIMES LIMITED, GOVERNMENT PRINTERS.
1909.

[G. 16—1909.]
£63-17-11

B.219.1475.09.
C.T.Ltd —B.273.

# Thirteenth Annual Report of the Geological Commission, 1908.

## CONTENTS.



## GEOLOGICAL COMMISSION OF THE COLONY OF THE CAPE OF GOOD HOPE, 1908.

### MEMBERS OF THE COMMISSION.

THE HON. JOHN XAVIER MERRIMAN, M.L.A.

THOMAS MUIR, C.M.G., LL.D., F.R.S.
Superintendent-General of Education.

THOMAS STEWART, M.I.C.E., F.G.S.

ATHELSTAN HALL CORNISH-BOWDEN, Surveyor-General.

FRANCIS EDGAR KANTHACK, A.M.I.C.E., Director of Irrigation.

*Secretary—*

THEODORE MACKENZIE.

### SCIENTIFIC STAFF.

*Director—*

ARTHUR WILLIAM ROGERS, D.Sc., F.G.S.

*Geologist—*

ALEX. LOGIE DU TOIT, B.A., F.G.S.

Cape Town,
March 22nd, 1909.

The Honourable
The MINISTER FOR AGRICULTURE.

SIR,—I have the honour to forward the report of the proceedings of the Geological Commission for the year 1908.

Every effort has been made during the year to see that the work should suffer as little as possible from the serious lowering of the grant which the Government felt itself constrained to make in July, 1908. Good progress has been made with survey work in the field: and an exceptionally large number of sheets of the Survey Map have been issued. Both these departments of effort give pleasing evidence of the zeal and devotion of the Staff.

Of the total number of sheets (52) into which the map is divided there have now been published eleven. It is thus regrettably clear that a considerable number of years must elapse before full information regarding the geology of the Colony will be available Such information being of economical importance any reasonable expenditure that might be required to accelerate the rate of production would soon justify itself.

I have the honour to be,
Sir,
Your obedient Servant,

THOS. MUIR,
Vice-Chairman.

# GEOLOGICAL SURVEY OF THE COLONY OF THE CAPE OF GOOD HOPE.

## DIRECTOR'S REPORT FOR THE YEAR 1908.

During the past year the work of the Survey has been carried on in the Divisions of Britstown, Prieska, Victoria West, Carnarvon, and Hay; and visits were paid to Knysna for the purpose of examining the re-opened lignite deposits, and to Prince Albert in order to see the evidence for a new interpretation of the geological structure of the southern edge of the Karroo.

I was absent on leave for two months at the beginning of the year, and subsequently spent 5½ months in the field. Mr. Du Toit was also engaged on field work for 5½ months.

When a commencement was made in 1899 in the survey of the northern part of Cape Colony only the outlines of the stratigraphy of the ancient formations had been described, by G. W. Stow; and it happened, as we know now, that the area selected (Prieska) is the most complicated corner of the immense district occupied by rocks of the Transvaal formation. The result was that several mistakes as to the relationships of the rocks were made, which only became obvious during the work in the north in 1905 and subsequent years, when the same formations in a comparatively undisturbed condition were mapped over many thousands of square miles. The report for 1899, too, had to be written before the rocks had been studied under the microscope, which was a serious inconvenience, considering the many extraordinary types of rock found in Prieska. To remedy these defects in the account of Prieska in the 1899 Report it was my intention to revise parts of the area myself on the way to the unsurveyed portion of Hay and on the journey to and from the Kenhardt Division, and that Mr. du Toit should do the same for the southern end of the ancient rocks. Owing to the drought in Kenhardt, however, I spent over three months in Prieska north of the road to Jackal's Water, while Mr. du Toit has gone over the whole of the district south of that road. Many difficult points were cleared up in the light of the experience gained in Griqualand West, Bechuanaland, and Gordonia, but there is still much to be done before some important questions, especially those connected with the metamorphic rocks of the central and western parts of the district, can be solved.

Much new information was obtained about the peculiar rocks allied to the kimberlite group, occupying fissures and pipes in Prieska, Britstown, and Victoria West.

With regard to the northern fringe of the Karroo formation south of the Orange River, it is unfortunate that the year's work only confirms the previous experience of this survey that coal does not occur in the black shales overlying the Dwyka boulder

beds. A gap of some 150 miles still separates these shales in the area examined last year from the outcrops near Loeries Fontein seen in 1900.

Sheets 42, 46, 49, 50, and 52 of the Geological Map were issued during the year. Sheets 33 and 41 will be issued shortly, and it is hoped that 32 and 40 will be completed this year.

Dr. F. L. Kitchin's Memoir on the Mollusca of the Uitenhage series has been issued in Vol. VII. of the Annals of the South African Museum, and a paper by Mr. F. R. C. Reed on new Bokkeveld fossils in Vol. IV.

We have to thank Colonel Close, C.M.G., R.E., and Captain Evans, R.E., of the Intelligence Department, for printed maps and photographs of manuscript maps of the northern districts, which have very greatly facilitated the field work.

Dr. van der Riet, of Victoria College, Stellenbosch, very kindly made five analyses of dolomitic limestones, which are incorporated in this Report.

ARTHUR W. ROGERS.

# GEOLOGICAL COMMISSION.

## General Abstract of Receipts and Disbursements for the Year ended 30th June, 1908.

| | £ | s. | d. | £ | s. | d. |
|---|---|---|---|---|---|---|
| To Government Grant ... ... ... | 2,000 | 0 | 0 | | | |
| „ Public Works Department for services rendered ... ... ... | 119 | 6 | 3 | | | |
| „ Sale of Wagon ... ... ... | 56 | 2 | 6 | | | |
| „ do. Oxen ... ... ... | 162 | 1 | 6 | | | |
| „ do. Maps ... ... ... | 7 | 6 | 6 | | | |
| „ Sundry Fees for services rendered ... | 43 | 12 | 10 | | | |
| | | | | 2,388 | 9 | 7 |
| „ Advances (Current), repaid by vouchers | | | | 191 | 1 | 8 |
| | | | | £2,579 | 11 | 3 |

| | £ | s. | d. | £ | s. | d. |
|---|---|---|---|---|---|---|
| By Balance, 1st July, 1907 ... ... | | | | 4 | 17 | 6 |
| „ Salaries ... ... ... ... | 1,000 | 0 | 0 | | | |
| „ Allowances (Personal) ... ... | 205 | 6 | 3 | | | |
| „ do. (Horse)... ... ... | 19 | 14 | 0 | | | |
| „ Transport ... ... ... ... | 50 | 0 | 10 | | | |
| „ Postages ... ... ... ... | 25 | 6 | 2½ | | | |
| „ Printing, Books and Magazines ... | 26 | 15 | 0 | | | |
| „ Rock Sections ... ... ... | 14 | 15 | 5 | | | |
| „ Boys' Wages ... ... ... | 71 | 10 | 0 | | | |
| „ do. Food ... ... ... | 26 | 1 | 0 | | | |
| „ Purchase of Donkeys ... ... | 85 | 0 | 0 | | | |
| „ do. Wagon ... ... | 81 | 6 | 0 | | | |
| „ do. Scientific Instruments ... | 7 | 8 | 0 | | | |
| „ Printing of large Scale Maps ... | 156 | 4 | 0 | | | |
| „ Equipment and Maintenance ... | 69 | 13 | 3 | | | |
| „ Description of Specimens ... ... | 34 | 3 | 11 | | | |
| „ Grazing for Oxen and Donkeys ... | 26 | 18 | 0 | | | |
| „ Food for Donkeys ... ... ... | 21 | 3 | 3 | | | |
| „ Extra copies of Annual Reports ... | 44 | 17 | 0 | | | |
| „ Fees paid to Staff ... ... ... | 43 | 12 | 10 | | | |
| „ Miscellaneous ... ... ... | 3 | 1 | 1½ | | | |
| | | | | 2,012 | 16 | 1 |
| „ Advances made ... ... ... | | | | 195 | 0 | 0 |
| „ Balance as per Cash Book ... ... | | | | 366 | 17 | 8 |
| | | | | £2,579 | 11 | 3 |

(Signed) THEODORE MACKENZIE, Secretary.

I hereby certify that the above Account has been examined under my directions and is correct, and that the balance agrees with that shown in the Bank Pass Book.

(Signed) WALTER E. GURNEY,
Controller and Auditor-General.

Cape Town, 15th August, 1908.

# REPORT ON THE GEOLOGY OF PARTS OF PRIESKA, HAY, BRITSTOWN, CARNARVON, AND VICTORIA WEST.

# REPORT ON THE GEOLOGY OF PARTS OF PRIESKA, HAY, BRITSTOWN, CARNARVON, AND VICTORIA WEST.

BY A. W. ROGERS AND A. L. DU TOIT.

## INTRODUCTION.

The country described in the following pages includes a strip of the Hay district from 10-20 miles wide, bordering the Orange River from Prieska to Buchu Berg, and extends southwards to a line from De Aar through Victoria West to Van Wyk's Vlei.

The Orange River traverses the district in a north-north-westerly direction, but only receives water from it during heavy rain. The chief hills are the Doornbergen, which trend north-west past Prieska to the Orange River at Westerberg; the south end of the Asbestos Mountains on the right bank of the river just below Prieska; the hill ranges with various directions east of the Langberg; the south end of the Langberg range and its extension in Ezel Rand on the left bank of the river; the long quartzite hills, which have no name, stretching from Keuk en Draai and Karee Leegte south-eastwards past Brakbosch Poort and Jackal's Water to beyond Jonker's Water, the irregularly placed hills marking outcrops of dolerite sheets in the southern part of the district, and the broken escarpment of the Beaufort sandstones running in a curve concave to the north from Philipstown to beyond Carnarvon. The hills made of the pre-Karroo rocks never rise to a greater height than about 4,200 feet, *i.e.*, some 1,200 feet above the Orange River at its nearest point; they have remarkably flat tops, although carved out of steeply inclined beds, and the average level of the flat tops does not increase regularly in any direction. In the area made of the Karroo beds the tops of the hills rise to heights of over 5,000 feet above the sea.

The formations which appear at the surface in the district are the following:—

*Recent* and superficial deposits, sand, limestone, etc.

| | | |
|---|---|---|
| Karroo system ... | Beaufort series.<br>Ecca series.<br>Dwyka series. | |
| Matsap series— | | |
| Transvaal system ... | Griqua Town series ... | Middle Griqua Town or Ongeluk beds.<br>Lower Griqua Town beds. |
| | Campbell Rand series.<br>Black Reef series. | |
| Ventersdorp system | Pniel series.<br>Zoetlief series | |
| Kheis series ... | Kaaien beds.<br>Marydale beds. | |

In addition to these there are several groups of intrusive rocks of various ages. The great granitic intrusions are younger than the Kheis series, but older than the Ventersdorp formation; the dolerites of post-Karroo age are important in the southern part of the area; besides these two large groups there are many intrusions younger than the Transvaal and probably also than the Matsap rocks, but older than the Karroo beds; and there are pipes and intrusions of various basic rocks related to the kimberlites.

A part of the district was described in the Annual Report for 1899, but that report was written before any of the rocks had been examined under the microscope, and before field work was done in the country north of the Orange River, where several of the same formations occur in a much less disturbed condition.

The points in which the results now arrived at differ from those obtained in 1899 are:—

(1) The age of the granite intrusions; in 1899 the granite was taken to be younger than the Transvaal formation, whereas now it is clear that it is older. This mistake originated first through the inclusion of the magnetic quartzites of the Marydale beds with the Griqua Town series, and secondly through a grey syenitic dyke on Uitspansberg, being taken for a granitic dyke belonging to the granites west of the Doornberg. Microscope work and the discovery of further syenite outcrops have enabled us to distinguish the two groups of intrusions.

(2) The isolated bands of magnetic quartzites are now clearly distinguished from the Lower Griqua Town beds. It is easy to be sure of their difference in age after knowing that very similar rocks in Bechuanaland are covered unconformably by the Ventersdorp system as well as the Transvaal system, and after a study of the rocks under the microscope. Further field work has shown that these isolated magnetic quartzites form part of one group with the basic granulites, the nature of which was unknown when the 1899 Report was written, and other rocks, and that this group is closely connected with the quartz-schists, Kheis beds of the 1899 Report, so that the term Kheis series is now extended to cover all these schists and granulites, the upper and lower sub-groups being termed the Kaaien and Marydale beds respectively.

(3) The complexity of the field relationships of the amygdaloidal diabase (Zeekoe Baart amygdaloid) led to its being regarded as an intrusive rock of later age than the Transvaal system in 1899. At that time we were ignorant of the exact character of the volcanic rocks

along the Vaal River described by Stow, for his description did not give enough particulars. From the results of the survey in Griqualand West and Bechuanaland, however, and a comparison of the rocks in hand specimens and thin sections there can be no doubt that the Zeekoe Baart amygdaloid is merely a part of the Ventersdorp system. The recent work in Prieska, too, has proved that conglomerates and tuffs are interbedded with the amygdaloidal lavas. The intricate relations of the rocks in Prieska are to be explained by faulting and folding. Certain areas of the rocks classed with this group in 1899, especially those amygdaloids on the western part of Prieska Poort, have been found to be a less altered portion of the Marydale beds.

(4) The use of the name Doornberg series as an equivalent for what is now called the Transvaal formation need not be retained, but in 1899 no single term for the formation had been proposed. Mr. Dunn's term Lydenburg beds included the Matsap group as well. The Campbell Rand beds in 1899 were held to include the quartzites near the base, which are now called by their usual name of Black Reef.

In 1905 Professor Schwarz published an account,[1] with a map, of the old rocks of Prieska, together with a correlation of the Pre-Cape rocks generally. The only point which need be noticed here in connection with that paper is that the grouping together of the Kheis series and the quartzites, etc., of the Black Reef group has not been upheld by subsequent work.

In view of the fact that the structure of the area made of the rocks older than the Dwyka series in Prieska is extremely complicated, it is advisable to write a general account of it free from the numerous details which have to be recorded, but which must obscure the main issues.

The oldest group of rocks in the district is the Kheis series, which includes a lower group of volcanic and sedimentary beds (quartzites, limestones, etc.), called the Marydale beds, and an upper group of quartzites and mica- and quartz-schists called the Kaaien beds. The largest area of this series is the hilly country extending south-eastwards from the Kenhardt border near Karee Leegte and the Orange River to Jonker's Water; this strip is the continuation of the belt of Kheis beds cut through by the Orange River above Upington.

The strike varies generally from S.E. to S.S.E., but north of Karee Leegte it turns east of north, and becomes more or less parallel to the strike of the Matsap beds in Ezel Rand.

This main area of the Kheis series is constituted almost entirely by the upper or Kaaien beds, though the Marydale beds

[1] The Transvaal Formation in Cape Colony. Trans. Geol. Soc. of S. Africa, VIII., 1905, p. 81.

are found along its north-eastern flank for several miles. The smaller areas of the Kheis series are found between the main belt and the Ventersdorp and Transvaal formations in the Doornberg region. Excepting a few strips of these beds lying in contact with the Ventersdorp, Transvaal, or Matsap beds, probably along lines of thrust, the Kheis beds are either in contact with granite or pass under the Dwyka. The granite contacts are seen to be intrusive junctions at many places both in the main area and in the isolated masses, the largest of which, made chiefly of highly altered volcanic rocks, stretches south-eastwards from near Vaalberg for some 24 miles past Grove's Puts and Alicedale to Groot Modder Fontein.

The intrusion is proved by the many cases of veins of granite and pegmatite in the older rocks, and by the great mineralogical changes they have undergone. In the case of the long belt of Marydale beds south-east of Vaalberg the degree of metamorphism increases from the north-east side to the south-west; the less altered basic lavas are hornblendic and schistose, but granulitic structure is best developed in the south-western part of the belt, where some of the rocks contain cyanite, staurolite, and sillimanite also. In the Zwart Kop outcrops some of the lavas retain traces of their original felspars, or the outlines are preserved even though the substance is altered, and the rocks originally diabases are epidiorites, but in other cases in the same group of outcrops hornblende-schists and granulites have been produced.

Summarising the observations made on the Marydale basic lavas, the least altered are epidiorites; hornblende-schists with or without epidote and often with much reconstructed felspar are a further stage, and the granulites the most advanced stage. The composition of these rocks evidently depended chiefly upon the composition of the lava when the alteration commenced, and the proportion of felspar, epidote, and garnet found in them indicate the extent to which the lavas were previously weathered. The explanation of the occasional predominance of augite over hornblende, and of other mineralogical peculiarities, is not so obvious, but the augite-bearing granulites are confined to the areas of greatest alteration. In all cases where lavas are spoken of the justification of the use of that term is the presence of spherical or flattened patches of pale minerals, mainly quartz, which seem to be explicable in no other way than on the assumption that they represent amygdales. In the case of the epidiorites no one would doubt this explanation, but in the hornblende-schists and basic granulites the bulk of the rock is so thoroughly changed in appearance that the origin of the colourness or pale patches is not so quickly realised.

A rock frequently met with in the Marydale beds, and also on the edges of the Kaaien areas where the Marydale beds are absent, is a grey banded granulite, varying in composition from a rock that has the same constituents as the granite to rocks that

are very largely made of quartz. It is probable that many of these grey granulites are sedimentary rocks which have received additional material from the granite. The presence of these granulites makes the separation of granite or gneiss from the quartzites in mapping a very difficult matter, for there is a series connecting the extremes, and the nature of individual specimens was only recognised on examination of thin sections under the microscope.

The granitic material which invaded the Kheis series has a gneissose structure in part, and the foliation planes lie parallel to the most prominent planes in the sedimentary rocks, but it is found that in such rocks as the magnetic quartzites the most prominent planes have been superimposed on an earlier system of folding with a different direction.

It is certain that the Kheis series had been greatly folded before the granite invaded it, and that it has been affected by earth-movements since that event, probably before and after the Ventersdorp and Transvaal formations were deposited, and certainly again after the deposition of the Matsap series.

The separation of the once continuous mass of Kheis beds into the various fragments mentioned above is due to the effect of denudation on a highly folded mass invaded by granite. From the evidence available it seems that the rocks of the Kheis series were already broken up in this fashion at the commencement of the Ventersdorp period.

The Ventersdorp and Transvaal formations are now restricted to the north-eastern part of the district, and they are unconformably overlain by the Matsap series on the north. The structure of the south-western side of the area made of these beds is very complicated; though probably not so complex as that made of the Kheis series, the fact that several horizons can be recognised with certainty makes the complexity more obvious and an attempt to explain the broad outlines possible.

Three distinct periods of disturbance have to be considered in this area; the first and least important was that during which the Ventersdorp beds were given various dips, and therefore subsequently the Black Reef beds were laid down upon different members of the system at various localities. To the second period of disturbance are due the broad anticlines and synclines in the Transvaal formation in Griqualand West with a more or less northerly trend; to this period the general synclinal structure of the Doornberg region also belongs, but the details were obscured first by the later and much greater movements in the south-western part of the region, and then by the cover of Karroo rocks not yet removed from the eastern portion; that these comparatively gentle folds were produced before the Matsap beds were deposited is proved by the fact that the latter rest unconformably on the different stages of the older rocks. The third period was the most important in this area, for to it belong the overturning and thrusting which complicate the structure of

the Doornberg and the country between that range and the end of the Langebergen.[1]

The Doornberg consists of an eastern nearly flat lying portion, a central anticline, and a western overturned syncline bounded and obliquely cut off in the south by the Doornberg fault. The Campbell Rand limestones are well seen at Zoet Vlei; they are brought to the surface again by the central anticline in Keikam's Poort, but are not seen at Prieska Poort, though they reappear on Glenallen as an overturned anticline widening out to the north-west. The Ongeluk lavas are seen in the trough of the western syncline on Keikam's Poort and again north of Prieska Poort; were it not for their occurrence here there would appear to be a continuous upward succession of the Griqua Town beds from east to west.

The western chain of hills is formed by a narrow belt of Griqua Town ironstones, Campbell Rand limestones, and Black Reef quartzites, all dipping at high angles to the south-west, the flats to the west being composed of granite and gneiss against which the quartzites are faulted. The belt varies greatly in its nature from point to point, owing to faulting. For some miles a fault separates the Black Reef from the Campbell Rand beds (upper portion), and the latter form a narrow strip, passing conformably into the overturned Griqua Town ironstones. In the southern portion of Prieska Poort first the limestones and then the quartzites are cut out, so that for a distance of three miles the ironstones are in contact with the granite. At the Poort the geological structure brought out by detailed mapping is very complex, and the bed of limestone which is associated with banded ironstone, green slaty rocks, and grits must probably be regarded as belonging to the Griqua Town series. From Prieska Poort to Uitspanberg the Black Reef quartzites form a belt about 400 yards wide faulted against the granite on one side and the Griqua Town beds on the other. The quartzites are nearly vertical, but are evidently folded. At a point not far from Uitspanberg there is a marked synclinal infold of Campbell Rand limestone; near Prieska Poort the road crosses a lenticle of amygdaloidal quartz-porphyry, felsite, and diabase, probably an inlier of Pniel volcanoes. Similar volcanic rocks form a streak between the limestone and banded ironstone below the north-western beacon of Keikam's Poort.

Along the western boundary of the Black Reef series narrow strips of the Marydale beds have been brought in by thrusting at three points, thus separating the Black Reef quartzites from the granite and gneiss; at another point there is a streak of

[1] The south-eastern part of the Doornberg is shown on Sheet 33 of the Geological Maps of the Colony (already published); the rest of the complicated country will be found in Sheets 32 and 40, which will probably be issued in a year's time; a small portion round the Zeekoe Baarts is given in Fig. 11 of this report.

amygdaloidal diabase occupying a similar position. The granite and gneiss have been sheared along the junction and converted into a fissile fine-grained material, mylonite; several belts of similar rock lie to the west parallel to the main fault, and in a few places streaks of quartzite are wedged in the gneiss.

There seems to be no doubt that the strata were closely folded, and that shearing took place parallel to the limbs of the folds, thus giving long, nearly regular belts of rock, bounded on one or both sides by faults; veins of white quartz are numerous along this fault zone under the Doornbergen.

The Campbell Rand beds on Uitspansberg are first seen as a narrow strip between the Black Reef and Griqua Town beds, but they suddenly widen out, and an apparently anticlinal band of Black Reef quartzite branches east-south-east from the main belt of the latter. The dips throughout this area are south-westerly. The overturned syncline marked by the occurrence of the Ongeluk lavas on Glenallen and Uitspansberg does not seem to be continued into the limestone area. On the western boundary of Uitspansberg, about a mile south of the N.W. beacon, the Black Reef belt contracts sharply, but in the hills north of Witfontein A it widens out to a band a mile wide, owing to folding, and the folds are not so closely pressed together as those in the higher beds on Glenallen and Uitspansberg. The syncline on the south-western side of this Black Reef belt does not bring in the Campbell Rand group, but the anticline on the north-east side is so wide and is cut down so deeply on Nauga as to allow the appearance at the surface of an elongated area of the Pniel beds two miles long. A second smaller anticline with a core of the latter beds occurs immediately north of the Wit Vley-Nauga beacon, but for three miles to the north-west the Black Reef belt is narrower, and is probably not folded, but dips at a rather high angle below the Campbell Rand group. Near the Springputs-Nauga beacon, however, the double fold begins again, and an anticline of Pniel beds is flanked on either side by the Black Reef for some 2½ miles. The north-east limb of the anticline disappears on Geelbecks Dam, cut off by the thrust fault, and the syncline on the south-west is similarly cut off by the same fault further south.

The Ventersdorp beds are first seen near the Uitspansberg-Witfontein boundary, where sheared quartz-porphyries appear, at first lying between the granite and the Black Reef, and further north-west separated from the latter by the amygdaloidal diabases.

On the south-western side of the Ventersdorp area the rocks are very much sheared throughout, and on their north-east boundary can be seen at places to have been thrust over the Black Reef beds (see fig. 10). For some four miles on Geelbecks Dam and Westerberg the Black Reef series disappears, and the Ventersdorp lavas have been thrust north-eastwards in contact first with the Campbell Rand beds and afterwards with the

Lower Griqua Town beds. For three miles both the Black Reef and Campbell Rand beds disappear at the surface. The Campbell Rand beds of this area commence at the axis of the overturned anticline on Glenallen, they form a wide area on Kalk Gat and Nauga, though a few anticlinal ridges of Black Reef beds appear through them, and abut against the boundary fault on Westerberg and Geelbecks Dam.

Near the river on Westerberg there is a hill made of the Black Reef quartzites, apparently a synclinal lenticle abutting against the Griqua Town beds, but flanked on either side by the Pniel lavas. From this neighbourhood the outer boundary of the Ventersdorp beds takes a more north-westerly and then a westerly course, bringing in a large area of blue-green lavas and slaty rocks on Kameel Fontein, Schalks Puts, Blink Fontein, Blaauw Puts, and Zeekoe Baart, while the chief zone of acute folds, and probably thrust faults too, maintains a N.N.W. course as far as Boven Zeekoe Baart. This great expansion of the Ventersdorp area is one of the most puzzling features in the district, for it is obvious from the cleavage planes that the Ventersdorp lavas etc., have been subjected to quite as much pressure as the steeply dipping beds of the same system and of the Transvaal system immediately to the east. One practical difficulty is due to the fact that the Ventersdorp beds have been cut rather flat, except in the hills near the Orange River, and the rocks are much hidden by sand, especially along the granite boundary beyond Schalks Puts. Whether there are inliers of granite is uncertain, they might certainly be expected on Blink Fontein and Zeekoe Baart, but they have not been seen.

The key to the puzzle is to be found in the southern part of the block of Zeekoe Baart farms. Here the N.N.W. trend of the axes of folds and the faults turns regularly round through north to N.E., E. and S.E.; the centre of this group of strikes is on Boven Zeekoe Baart, where narrow strips of the Lower Griqua Town beds extend from the Stilverlaats hills westward (see fig. 11), and gradually disappear between faults or infolds. A very interesting section is exposed on the cliffs of the right bank of the Orange River on Boven Zeekoe Baart (fig. 1). Two bands of Black Reef quartzite are separated by a wedge of Campbell Rand limestone from the overlying Lower Griqua Town beds, which are overlain by the Campbell Rand beds. The Black Reef and Lower Griqua Town beds make prominent outcrops, but the limestones are cut back. Whether the junctions are called faults or overfolds is not of much consequence, as if they are folds great thicknesses of rock must have disappeared owing to their slipping away along the junctions. The bedding in the quartzites is regular, and no folds were seen; the limestones are not so regular, but the greatest amount of puckering is in the Lower Griqua Town beds.

This structure is a well-exposed example of what occurs repeatedly on the Zeekoe Baarts, but further north and northwest the Ventersdorp and Matsap series are also involved, and

as in most cases the rocks are only seen in plan, it is more difficult to understand the details.

The Lower Griqua Town beds occur at three places on the left side of the river here; in a small oval patch 200 yards long and 150 wide in the limestone at the top of a hill overlooking the river between Consente Kraal and Zeekoe Baart; the second is in the limestone below the Matsap beds in the bay of Ezel Rand, where they are 400 feet thick, though much folded on a small scale, and about half a mile long, with the Campbell Rand limestone on each side; and the third is a smaller mass of highly-sheared haematite-quartz rock further north-east under Ezel Rand.

The outcrops of the Ventersdorp and Matsap rocks are described in detail elsewhere in this Report. It is obvious that the Matsap beds have been affected by the powerful thrusting from the west and south-west, and there is no reason to suppose that the thrusting along the south-west of the Doornberg


FIG. 1.—Section seen on the Orange River on Boven Zeekoe Baart. C. Campbell Rand series; B. R. Black Reef, L. G. T. Lower Griqua Town beds. F. Faults. Distance about 500 yards.

and the country to the northwards took place at an earlier date. The evidence from the distribution of the rocks on the Zeekoe Baarts is all in favour of the view that there was only one period of thrusting. Had the rocks been first given a N.N.W. strike and had long afterwards, during post-Matsap time, a new thrusting process begun from the north-west, the result must have been even more complex than the rocks show now.

## THE KHEIS SERIES.

In former Annual Reports[1] this series included rocks that are chiefly quartzites and quartz-schists, and which occur in the hills running north-north-westwards from south of Jonker Water to the Orange River at Kheis, along the river to the neighbourhood of Upington, and again at Scheurberg and a few other localities in the Kalahari. The past season's work has shown that the peculiar basic granulites of the Prieska district and other varieties of rock associated with them are so closely connected with the typical quartz-schists of the Kheis series that

[1] Ann. Rep. Geol. Com. for 1899, p. 73; and for 1907, p. 15.

it is advisable to use that term to include the granulites, etc., as well as the quartzites and quartz-schists. This larger group then falls into two divisions, a lower group containing the granulites, etc., called the Marydale beds, and an upper group, the quartzites and quartz-schists, which can be named the Kaaien beds.

The Kheis series in Gordonia is invaded by granite, as shown in last year's Report, and the same is the case in Prieska, where granite and gneiss occur on both sides of the large area made of the series, which has smaller masses and veins within it. There are also many large and small masses of Kheis rocks lying entirely surrounded by the granite between the western hills and the Doornbergen.

The relative positions of the Marydale and Kaaien beds are not known with certainty, because no normal base to the formation has been found; there are no rocks within the district that can be shown to be older than the Kheis series, though the character of the greater part of the latter proves that there must have been a land made in part of granite rocks, by the denudation of which the great mass of sediments originated. The Marydale beds are presumed to be the older of the two subgroups, because they occur on the outer sides of the main area of the Kheis beds in contact with the granite, which in places breaks through them to the Kaaien beds, and because there are several large masses of Marydale beds lying entirely within the granite [illegible]. It is [illegible]ly that the group most closely associated w[illegible] be the older of the two.

[illegible] presence of detrital rocks, consisting largely of granite [illegible] which is itself invaded by granite, is of great importance, because it proves that there must be granites of two ages in the north of Cape Colony, the one older and the other younger than the Kheis series. Though these two granites have not been clearly recognised, it is worth while pointing out that the granite of Mafeking and Vryburg has not been proved to be intrusive in the Kraaipan series, which certainly presents points of great similarity to the Marydale beds. Some of the junctions of the Kraaipan series with the granite are believed to be unconformities, and if this proves correct, then that granite may be part of the mass which formed the land from which the Marydale beds received their sediments. Whether the Kraaipan and Marydale beds are parts of one formation or not is as yet unproven, but there is sufficient resemblance between them to make their correlation probable.

Another interesting question concerns the possibility of the correlation of the Wilgenhout Drift[1] and the Marydale beds, but until the relation of the former to the Kheis beds in Kenhardt have been discovered there is no definite evidence. The conglomerate found in the Wilgenhout Drift beds on Zwart Kop contains quartzite pebbles of unknown origin.

[1] Ann. Rep. Geol. Com. for 1907, p. 35.

### *The Marydale Beds.*

The rocks assigned to this group occur on the eastern side of the ranges of Kaaien beds on Blaauw Puts, and again from Brul Pan past Marydale (a village built on the belt, whence the name of the group) and Stuurman's Puts to Wit Vley; on the eastern side of the same hills on Jackals Water; in a long belt extending from Vaalberg to Groot Modder Fontein, at Zwart Kop north of Draghoender, and in several other localities between the Doornbergen and the Kaaien hills.

The Marydale beds include rocks of undoubtedly sedimentary origin such as quartzite, limestone, slates, and arkose, and a great variety of lavas, which have to a great extent been converted into hornblende-schists and granulites. The proof of these rocks having had a volcanic origin lies in the repeated occurrence of amygdaloidal structure in them, and the general character of the least altered lavas. In composition they range from acid quartz-porphyries to basic rocks.

Whether some peculiar basic granulites on the western side of the Kaaien hills belong to the Marydale beds is still uncertain.

Rocks which can be regarded as forming the lowest portion of the Marydale series in this district appear as a number of detached inliers in the Dwyka close in under the Doornberg on the farms Zoet Vlei, Welgevonden, and Groot Modder Fontein.

At the pan on Zoet Vlei these beds may possibly be faulted against the Griqua Town ironstones, otherwise the surrounding (pre-Karroo) rock is granite and gneiss. The area which they form (fig. 2) is elongated and tapers to the north-west; its manner of termination to the south-east is problematical.

In spite of the limited and sometimes distant outcrops, a definite sequence of beds can be made out. At the base comes a considerable thickness of arkose with some grits and phyllites, followed by cleaved igneous rocks, for the most part probably of volcanic origin, varying in composition from acid to ultrabasic. Intercalated between the volcanics are layers of banded ironstone (magnetite-quartz-schist), which form black ridges and show marked folding and puckering. The general structure of this belt is a synclinal one, but the isoclinal type of folding is common along its axis.

The arkose is a coarse-grained rock, sometimes carrying pebbles, bluish grey when fresh and very uniform lithologically. The bedding planes are very feebly developed, and have, in the highly schistose varieties, been totally obliterated. On Welgevonden (South) on the edge of the pan is a finely glaciated hummock of this arkose, on the south-west side of which the following succession of vertical beds is seen: quartzite 2 feet, diabase 6 feet, quartzite 6 feet, diabase 6 feet, slaty band 3 inches, grits 7 feet, passing into arkose. The junctions are all remarkably sharp, and the diabases are probably contemporane-

ous lava flows. Where the arkose has been weathered it projects above the surface in jagged ridges: this is especially well seen on the boundary between Welgevonden and Groot Modder Fontein. This is again the case close to the southern beacon of Zoet Vlei; and here the rock contains pebbles scattered through it, but these are most numerous along one particular horizon. They attain a size of five inches, and are usually well rounded and water-worn. Pebbles of white or blackish quartz predominate, but there are some of a very fine-grained, light-coloured rock, which proves (2253) under the microscope to be a crushed and devitrified quartz-porphyry or rhyolite.

A section (440) of the arkose from the west end of Zoet Vlei shows the following features under the microscope. The quartz grains are somewhat crushed, but not to any marked degree. felspars are principally orthoclase and microcline in rounded grains, which also exhibit the effects of crushing. Films of sericitic mica cross the felspars in places and separate the constituent grains of the rock. In slide (443), however, the quartz has been reducd to a finely granulitic mass; the felspar, chiefly microcline, has not been so much affected. The rock at the south beacon of Zoet Vlei has been much altered (1964-5). The felspar has been entirely converted into sericitic mica, which forms thick layers between the quartz grains; some of the latter contain flakes of original muscovite.

In this locality the passage into a green phyllite can be clearly seen, the latter being followed by a great thickness of cleaved igneous rocks, which project from the ground with jagged edges. On a larger scale this succession, clearly repeated again and again by folding, can be studied in the western portion of Zoet Vlei, and south of the main road, where the strata are well exposed for a distance of about a mile across the strike.

Here, too, the volcanic rocks have retained their original structures to a greater degree than in the ridges to the south-east. Amygdaloidal structures are well preserved in some cases, in others there is a partial obliteration, as the result of the pressure which produced the cleavage. For example, a band of grit was found dipping at an angle of 30° and resting on amygdaloidal rocks. The cleavage planes in the latter are almost vertical, and the amygdales flattened in this direction.

This cleavage is very marked in the ridges south of Zoet Vlei pan, the strike being north-north-west; but by carefully following certain types of rock it can be seen that the true strike of the beds is north-westwards, and that the apparent dips are fallacious.

A porphyritic diabase (1967) at the pan on Zoet Vlei has the felspar phenocrysts much altered and clouded and crammed with granules of epidote. Actinolitic hornblende is abundant in green aggregates, sometimes showing a deeper green colour. It is not unlikely that the actinolite has been derived in part or wholly from augite.

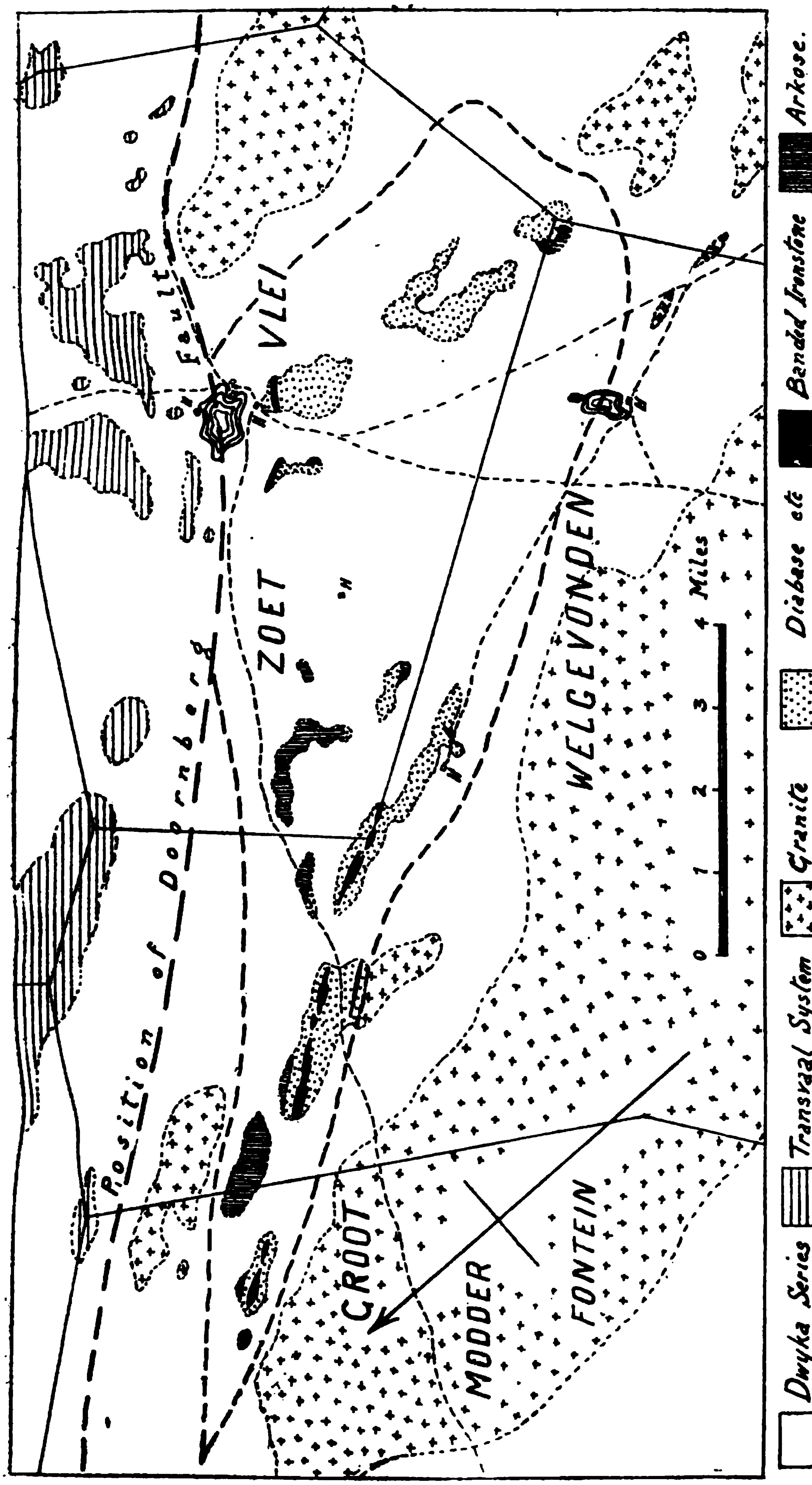



FIG. 2.—Plan of outcrops on Zoet Vlei, etc.

Magnetite occurs in large areas, much broken up. The groundmass consists of clear quartz and albite, with abundant inclusions of actinolite, epidote, and zoisite.

Acid lavas are not uncommon, and as far as can be judged occur on a horizon not far above the arkose. An example (1966) from the south beacon of Zoet Vlei is a flinty-looking rock, which under the microscope still shows lath-shaped felspars, but the fine-grained groundmass is full of granular quartz and sericite tufts, and has a markedly schistose structure. A specially fine quartz-porphyry along the road not far from the Groot Modder Fontein boundary shows (1969) blebs of quartz and *slightly* clouded orthoclase phenocrysts in a very fine-grained aggregate of quartz, felspar, and white mica.

Though the great bulk of the green diabasic rocks appear to be lava flows, it is not unlikely that some intrusive sheets are also present, for certain varieties are very coarse grained and devoid of vesicles. At Zoet Vlei veins of "asbestos" (tremolite) have been found in some basic and ultrabasic rocks, which, though they have not been separated from the surrounding diabase, are possibly intrusive.

Banded ironstone forms a bed about 200 feet in thickness in this locality, but better sections of this type of rock are to be found at the opposite end of this belt, where there are several bands separated by pale green schistose diabase or epidiorite. The folding is almost always of an isoclinal nature, the dip of both limbs of a synclinal fold being to the south-west, and the under limbs having the lesser inclination. These ironstone bands are synclinal infolds, and they form the ridges, but on the lower ground along the same strike they are not represented.

This ironstone horizon appears on the northern portion of Uitspanberg, a distance of about 27 miles to the north-west, while a parallel belt is found at the pan on Groot Modder Fontein.

No granite veins were noticed in the rocks of the Zoet Vlei belt, and the granite contact was only found at one locality, near the main road on Welgevonden, and the junction may possibly be a faulted one, for the granite possesses a well-developed platy structure along its margin.

At Great Modder Fontein the Marydale beds appear, forming a belt which has a maximum width of five miles, gradually contracting as it is followed north-north-westwards to Uitspansberg. This great width is due first to folding and faulting, and secondly to the appearance of higher zones; the belt is bounded on either side by granite, and shows a progressively increasing metamorphism from east to west.

On the north-east side of the Groot Modder Fontein pan the rocks are tough cleaved diabases, darkish in colour, with a prominent bed of lighter coloured amygdaloidal rock and some thin bands of grey grit. The actual junction with the granite is not exposed here, but further to the north, along the main road to

Prieska Poort, the volcanics are more altered and schistose, alternating with belts of gneissic granite, and ultimately streaking out in the latter.

A coarse rock from the easternmost outcrop near the pan proves in thin section (2002) to consist mainly of green actinolite in large areas, fringed with a greener hornblende; it seems to have been derived from augite. There are areas of quartz and felspars, which in places exhibit a micrographic intergrowth, almost the only original structure that is still preserved. The felspar, however, is crowded with needles and blades of actinolite. The iron ores possess geometrical outlines, but have been broken up and the spaces filled with actinolite.

A light-coloured, compact rock (451) consists principally of aggregates of epidote and prisms of zoisite in a groundmass of polygonal areas of quartz, with blades of actinolite and patches of calcite.

A schistose rock (2001) close to the contorted banded ironstone on the ridge overlooking the pan must originally have possessed a porphyritic structure. Actinolite in rods and prisms is aggregated together to form large elongated areas, with rounded ends; they contain numerous granules of epidote. The groundmass is of granulitic quartz and water-clear felspar, in which are set "eyes" of plagioclase, evidently re-crystallised phenocrysts, for they are penetrated by actinolite needles and bordered by small quartzes, which encroach on them. The iron ores form irregular areas.

West of this ridge the rocks become darker in colour and more completely re-crystallised. The actinolite builds up definite crystalline areas, garnet may develop, while often the iron ores are converted into sphene. Ultimately granulitic hornblende schists, with or without garnet, are produced, and the only traces of their volcanic origin is to be found in the quartz-filled amygdaloidal cavities, which have frequently escaped obliteration.

*The Vaalberg-Groot Modder Fontein Belt.*

The greatest development of the Marydale beds is in a belt extending from a point close to Vaalberg down to the pan at Groot Modder Fontein.

On the east side the boundary against the granite is remarkably even; the Marydale beds along it being principally black hornblende-schists, traversed by veins of white quartz, which are very conspicuous a few miles from the northern beacon of Jackals Water. These rocks form flattish ground, which is strewn with boulders weathered from the Dwyka, while there is a considerable development of tufa in places.

On the western side of the belt the ground is more broken, and there are numerous strips of quartz-schist and grey granulite enveloped in the granite and gneiss, and separated by the

latter from the basic schists and granulites. A patch of dark micaceous schist in the granite a little north of the north-eastern beacon of Jackals Water contains andalusite and sillimanite. The thin section (1987) shows a granulitic aggregate of quartz full of ragged flakes of green biotite mica, with a smaller amount of muscovite. Colourless andalusite forms most irregular areas, enclosing quartz; it is intergrown with biotite and sillimanite, the latter in needle-shaped crystals. Granules of iron ores, sphene, and zircon are abundant in the biotite.

The quartz-schists and grey granulites have numerous veins of granite parallel to the strike, less commonly cutting across the bedding. Generally, the granite is coarse in grain quite close to the junction, while biotite is scarce; at quite a number of places it is pink in colour, and it is occasionally porphyritic.

In the gneiss about a mile W.N.W of Water Kop on Jackals Water there is an interesting occurrence of amygdaloidal hornblendic rock, quartzite, and mica schists, represented in plan by Fig. 3. The quartzite and mica-schists grade into one another, and both are penetrated by veins of pink gneiss of various dimensions; some are less than half an inch wide. A thin section from a quartzite traversed along the strike by thin pink veins (2212) shows that the rock is made of fairly uniformly sized grains of quartz, with smooth outlines generally, but in places the sutured type appears, small flakes of both white mica and greenish-brown biotite, a little epidote and zircon, and grains and crystals of magnetite; the mica flakes are so small that they frequently lie within the thickness of the slice; they lie parallel to the strike of the beds. The pink layers are made of a finer textured rock, consisting of quartz, microcline, albite and muscovite. The distinction between the felspathic layers and the quartzite is obvious in thin section, though the former are often very narrow, owing to the difference in texture and the absence of felspar from the coarse quartzite. Another slice (2214) of quartzite from within an inch or so of the gneiss has a rather coarse granulitic structure, and the constituents are chiefly quartz, much less untwinned felspar, epidote, and magnetite, and a little white mica.

The hornblendic rock, of which there are two masses, one quite small and the other about 55 yards long, is penetrated by two veins of granite; the amygdales are abundant in parts of the outcrops. Under the microscope (2213) the rock is seen to consist of a fine-grained mosaic of quartz and albite, with magnetite and very small grains of zoisite (?) but no epidote, and much pale greenish blue hornblende, which occurs chiefly in elongated prismatic sections, but without well-developed faces; some of the hornblende is partly coloured and partly colourless, though the two kinds have the same extinction angle (up to 18°); quartz and magnetite are sometimes enclosed by the hornblende, but this structure is not nearly so well developed as in many of the basic granulites. The amygdales are represented by areas

in which the quartz individuals are much larger than usual, and are accompanied by a much less quantity of hornblende than is elsewhere present; felspar is only seen in very small amount in these amygdales. In a slice cut from a specimen showing a con-

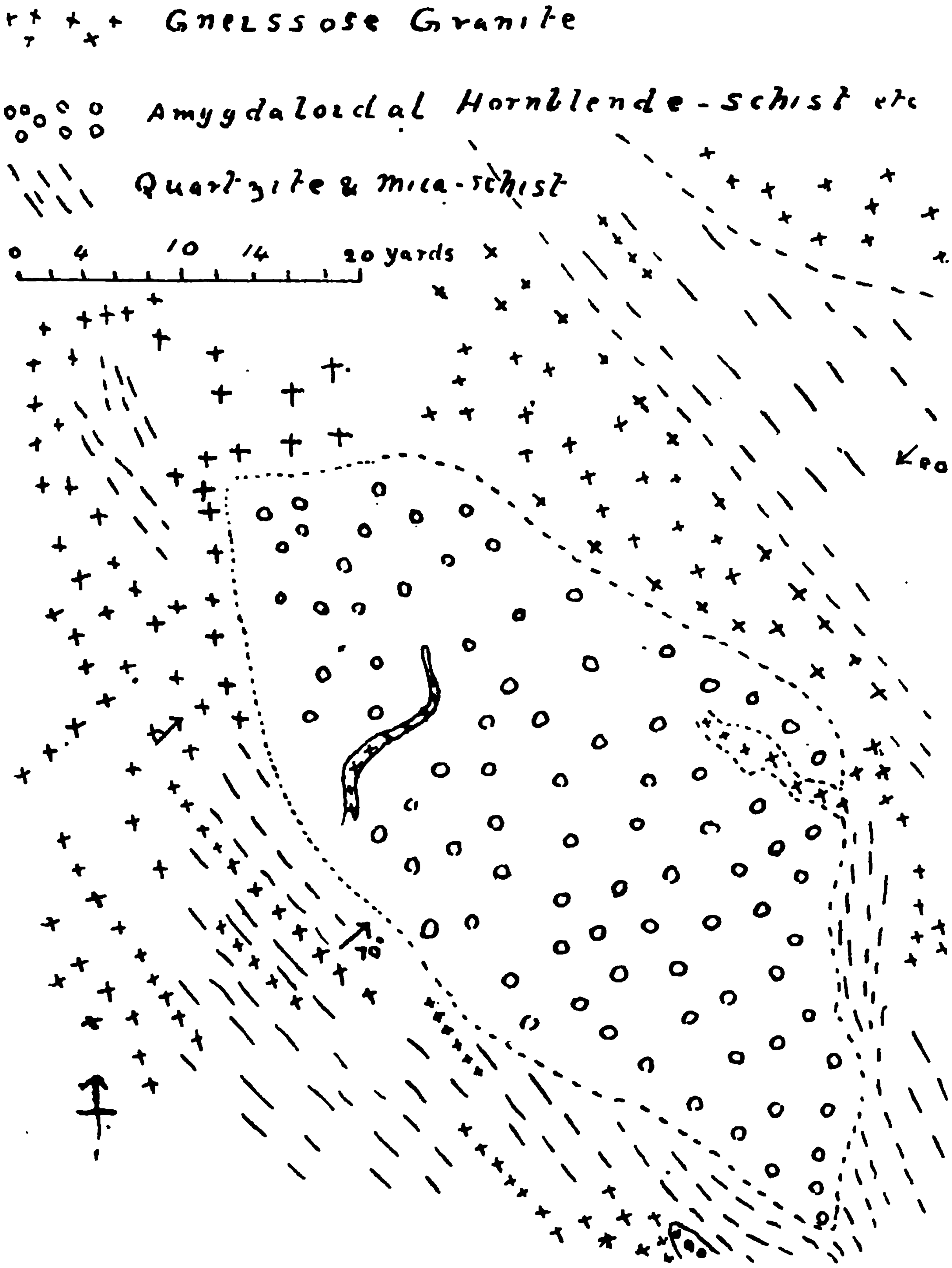



FIG 3.—Outcrops on Jackals Water.

tact of the dark rock and a vein of granite (2224), the former presents considerable differences from the rock just described. The dark rock is made of quartz, plagioclase, brown-green biotite, magnetite, a little tremolite, and small crystals of cyanite. The rock is quite different in character from the hornblende schist itself, though it was taken in the field to be merely the

edge of the latter. Possibly it may be an altered part that contained less lime, and therefore biotite was formed instead of hornblende. The granite is a quartz-orthoclase-albite rock without mica, both with cyanite and needles of fibrolite.

From Water Kop the granite forms a long tongue, striking southwards towards Uitzigt, and crossing the quartz-schists diagonally. Between Uitzigt and Alicedale there is a continuous succession from the main area of basic granulites through an alternation of grey granulite, quartzite, and basic granulite, into the typical quartz-schists of the Kaaien beds. Along the boundary between Groot and Klein Modder Fontein another wedge of granite intervenes between the acid and the basic granulites, attaining a width of a mile and a half.

The hill known as Water Kop is a dome-shaped gneissic complex, into which the acid granulites enter. There is every variation from muscovite and biotite gneiss to granulite; there is a marked banded or streaky structure, and the whole is cut by granitic veins.

In marked contrast to the regularity of the main belt of Marydale beds are the rocks along its western border. The complexity due to the numerous lithological variations of the original material, the differences in their metamorphism, and the modifications both of the Kheis beds and of the invading granite due to the inter-action of the two rocks prevent a detailed account of this zone, and it will be more satisfactory to describe the characters presented by the rocks in certain localities only.

Close to the north-eastern beacon of Jackals Water there was found a black granulite, undoubtedly intrusive, in quartz-schists, and interesting in that it could not be distinguished from many of the granulites of the main belt. The section (1998) shows complete recrystallisation of the rock, the green hornblende tending to form granular masses set in a fine-grained mosaic of quartz and plagioclase felspars, along with magnetite and prisms of clino-zoisite.

On the right-hand side of the road from Jackals Water to Prieska Poort there is a patch of quartz schist enveloped by granite. The granite material has permeated the sedimentary rock, and has in places formed "eyes" of felspar; elsewhere the quartzose rocks have been converted into streaky granulites. A section of one of these (1995) consists of a granulitic mass of quartz, orthoclase, microcline, and albite, with a good deal of muscovite mica; in it is a large crystal of microcline. There are a few garnets surrounded by epidote. Further south along the eastern boundary of the granite belt, on Alicedale, there is a narrow belt of amygdaloidal granulite separating the former from grey granulite and quartz-schists. The granite is pink in colour at the junction, and massive; it sends pegmatite veins into the granulite; further away it is greyer in colour, contains biotite, and becomes gneissic. The amygdales in the granulites are in many cases hardly distorted,

as, for example, in (2266). This shows oval "vesicles" filled with a mosaic of quartz and plagioclase felspar, with a few grains of hornblende or augite; the centre of each amygdale is commonly formed by a few large quartz individuals. The rest of the rock is composed of green granular hornblende, pale augite, with some plagioclase felspar and a few small patches of ilmenite, which are usually surrounded by a thin shell of sphene. The original rock must have been highly vesicular in character.

The low ridge between Alicedale and Uitzigt is formed of grey granulite, with a few bands of basic granulite, some of which exhibit similar amygdaloidal structures. Not uncommonly there appears to be an insensible transition from the basic granulites, presumably of igneous origin, and the grey ones, obviously altered sediments. Some of the rocks may have been tuffs, and in their metamorphism long prisms of hornblende have been developed (2264), which may contain so many inclusions of the groundmass that they are often mere skeletons. The bulk of the groundmass is composed of quartz; felspar, plagioclase chiefly, forms minute irregular areas arranged in strings; it is present in rather limited amount along with epidote. Another section (2266) shows larger hornblendes, in which detached irregular areas behave usually as portions of one crystal, but there is much more felspar present in this rock. Both the rocks contain a good deal of iron ore.

On either side of the granite between Klein and Groot Modder Fontein there are highly altered sediments, garnetiferous mica-schists, and grey granulites, very much altered and injected with granite and pegmatite—indeed, the permeation with granitic material has been so complete that it is very difficult to draw any sharp boundary between one rock and the other. Usually, however, in the altered sediments the bedding planes are still preserved.

A specimen taken from along the road crossing the ridge, along the eastern side of the granite, shows in thin section (2263) a granulitic mass of quartz, orthoclase, and plagioclase felspar, in which are set garnets with extremely irregular outline and full of numerous inclusions of quartz and felspar.

A micaceous rock taken from a point a little to the north of the road contains cyanite, staurolite, and garnet, and is evidently a sedimentary rock which was in process of absorbtion by the granite. The thin section (1973) shows quartz in polygonal grains and a plagioclase felspar (andesine). There is a little muscovite mica and a great amount of greenish biotite in curved plates sometimes enclosing the muscovite. The garnets are large and pink in colour, and contain quartz inclusions. Cyanite is very abundant both in small and large prisms, with irregular ends; the larger crystals are intergrown with biotite. Staurolite is present in irregular areas, and is intergrown in parallel position with cyanite. It contains numerous quartz inclusions, and

is pleochroic, from nearly colourless to deep yellow. The quartz and felspar are penetrated by bundles and radial aggregates of blade-like crystals of a mineral which is probably sillimanite. There are some large ragged patches of iron ores and a little apatite.

A remarkably similar type of rock was obtained about a mile to the east, in the midst of the garnet-granulites, and will be described here for comparison, although it really forms part of a small granite intrusion in the latter. In the thin section (2262) the quartz and plagioclase form a more granular groundmass. Muscovite mica is nearly as abundant as biotite; cyanite is intergrown with staurolite, but the relative proportions of the two minerals is now reversed. Sillimanite is abundant, forming whisp-like masses (fibrolite), developed especially around the cyanite, but also included in the muscovite. Apatite and magnetite are present as before.

The main belt of basic granulites is remarkable for its regularity and for the insignificance of the granite and pegmatite intrusions within it, the only occurrence worth mapping being that close to Wit Dam, between Jackals Water and Uitspanberg.

Crossing the road from Prieska Poort to Jackals Water on the east side of the belt, and east of the small homestead known as Grove's Puts, there is a zone of amygdaloidal diabases, showing comparatively little metamorphism. They are fine-grained, dull green rocks, with large amygdales of quartz, epidote and calcite. A thin section (671) shows tiny prisms of actinolite and irregular areas of epidote set in a mosaic of quartz, the epidote having been formed at the expense of the original felspar. The vesicles are filled with quartz, epidote, and clinozoisite. Along with these lavas are dark schists composed of chlorite, with some magnetite, the latter sometimes in octahedral crystals.

Approaching the Prieska Poort granite the amygdaloids become more metamorphosed. A thin section (676) of one variety has long prisms of hornblende, sometimes skeletal in habit, irregular areas of epidote, and small ragged biotite micas set in a quartz mosaic. The vesicles are filled with quartz, epidote, and calcite, and the rock is traversed by narrow quartz veins.

Just west of Grove's Puts and south of the road is a chain of low hills formed of massive serpentine, flanked by talcose schists. These probably represent an intrusion in the Marydale beds.

Towards the granite boundary on Jackals Water the intensity of the metamorphism increases, and the hornblende-granulites are frequently garnetiferous. Along with these altered igneous rocks are others, probably of sedimentary origin. They are slaty in character, and small garnets stand out on the cleavage surfaces. A section (2215) from a well just north of the road shows pink garnets full of inclusions embedded in a matrix of granulite quartz and films of muscovite and pale greenish biotite. Flowing round the "eyes" of garnet and attached to the latter,

sometimes on one side only, there is clear granulitic quartz. The garnets contain numerous inclusions of quartz and iron ore, which are arranged in a regular manner in strings conforming with the foliation in the surrounding rock. Small irregular plagioclase felspars form "eyes," and are either of clastic origin or, more probably, have been developed from felspathic material in the original slate. There are a few irregular grains of staurolite, while smaller cyanites are abundant; granules and octahedra of magnetite and grains of apatite are numerous. A nearly similar rock was found in a well about four miles to the north, and possibly comes from the same horizon. The thin section (1986) has been cut parallel to the foliation, and therefore does not show this structure well. The garnets are large and full of small inclusions; the felspars are again mostly rounded, and are plagioclase. The groundmass is like that of a hornfels, a mosaic of quartz, overlapping plates of a greenish biotite, and grains of iron ores, and in it are set large, irregular individuals of cyanite and numerous minute prisms of the same mineral.

Down the western side of the belt the black amygdaloidal granulites are finely developed; they can be specially well studied in a little kopje which rises from a flat a little to the north-west of the homestead on Alicedale. The amygdaloidal structure is as well developed as in any of the Pniel lavas, and in some places the appearances suggest metamorphosed brecciated lavas and volcanic breccias. The granite veins cutting the hornblende granulites frequently contain large crystals of black hornblende.

West of the pan on Groot Modder Fontein there are various hornblende granulites, cut by a few veins of granite and pegmatite, the latter often carrying biotite and garnet.

Interbedded in these is a band, about 18 inches thick, of a cream-coloured rock full of minute garnets, and probably originally a bed of sandstone, the thin section (1974) shows a granulitic mixture of quartz and a basic oligoclase felspar, the former predominating. The garnets are more or less idiomorphic, and there is a small amount of muscovite and biotite mica.

Of the hornblende granulites there are many varieties, one of the most striking being garnetiferous, and in which the hornblende crystals attain a length of over an inch in places. A section of this rock (2261) shows those peculiar, almost skeletal, crystals of green hornblende set in a finely granulitic mass of quartz and a plagioclase felspar, the latter being frequently zoned. The garnets exhibit crystal faces; the iron ore is full of little inclusions of quartz. There are abundant minute granules of epidote, usually formed round a core of a brown mineral which resembles allanite, except for the absence of pleochroism.

Another variety apparently identical in the hand specimen

proves, however, in thin section (1970) to contain enstatite forming a core to the prisms of hornblende, the proportions of the two minerals being about the same. In (1971) the hornblende forms a number of little irregular patches, which have the same or nearly the same optical orientation over large areas; the rock is peculiar on account of the large amount of plagioclase felspar in it full of sharply bounded granules of zoisite and epidote and numerous little blebs of quartz. The grains of iron ore have been recrystallised, and possess inclusions of quartz and zoisite. Another granulite is peculiar in containing large twins of, probably, original felspar, in all likelihood orthoclase, now replaced by an aggregate of sericite.

Amygdaloidal granulites, some of which are garnetiferous, are well represented in this locality, the quartz amygdales being often pulled out into long streaks.

One of the most interesting features in this belt is the occurrence of a narrow zone of quartz-schist, crystalline limestone, and banded ironstone, which lies near the homestead on Alicedale. Just north of the road from Jackals Water to Prieska Poort a thin band of grey limestone makes its appearance in the hornblende granulites. About a mile south of the road the banded ironstone begins as a thin ferruginous layer overlying the limestone, the latter being probably less than 15 feet thick and much folded. As these beds are followed southwards, they thicken somewhat, and the banded ironstone or magnetic quartzite forms a low ridge. Separated from the limestone by a band of black granulitic rock, there is a narrow belt of white or pale greenish quartzite and quartz-schist, usually very badly exposed; at a point little more than a mile north of Alicedale the quartzite shows some highly garnetiferous mica schist at its base, the garnets weathered out from this bed being sometimes two inches in diameter. Further to the east come hornblende granulites again; to the west the magnetic quartzite is overlain by granulites, sometimes amygdaloidal and frequently garnetiferous. These four bands of rock are sharply defined one from the other, and maintain their lithological characters over a distance of twelve miles. From a point two miles north of Alicedale the whole succession is duplicated by a strike fault, and some detailed mapping around the homestead showed that the individual beds are in places isoclinally folded, and that the thickness of the four bands together probably does not exceed 300 feet. The area to the south-east is much covered with tufa and boulders from the Dwyka, but the zone was located in a small stream course, which enters the pan on Groot Modder Fontein. The banded ironstone is about to die out; it is very thin, and passes into a coarse quartzose rock with variably distributed magnetite. The limestone has disappeared, but the quartzite and quartz-schist are well developed. On the west there is a continuous section of granulites right up to the

granite; on the east the zone is duplicated by an anticlinal fold, followed by a thrust, by which the rocks are brought into contact with the hornblende-schists and magnetic-quartzites forming the ridge at Groot Modder Fontein.

The magnetic-quartzite at Alicedale is less ferruginous than is the case with the ironstones elsewhere in this formation. The limestone is a light grey rock weathering with a pinkish brown crust. In a few places contact minerals have been developed in it by the action of the granite in the neighbourhood; about a quarter of a mile south of Alicedale a narrow vein of garnetiferous granite cuts diagonally through the granulite below the limestone. A section (1987) of a grey limestone shows interlocking areas of twinned calcite, in which are set long plates of tremolite, granules of colourless diopside showing alteration along cracks to serpentine, and numerous grains of iron ore. A section (1988) of a lime-silicate rock north of Alicedale shows calcite full of little spots of iron ores, in which are set large and slightly irregular crystals of colourless clino-zoisite, with inclusions of calcite and iron ore. Haematite has formed in spaces between the minerals.

The black rock immediately below the limestone was taken in the field for one of the usual hornblende granulites, but proves in thin section (1999) to be a unique type. The bulk of the rock is composed of clear pale yellow epidote, enclosing irregular areas or aggregates of quartz. The epidote is intergrown in parallel position with a smaller amount of deep green hornblende. Felspar is absent; octahedra of magnetite are numerous. The quartz-schists adjoining this rock are very like some in the Kaaien beds. A garnetiferous variety shows under the microscope (692) innumerable minute garnets, tending to come together in patches set in granulitic quartz with some flakes of muscovite.

On the ridge overlooking the pan the banded ironstones can be well studied; the layers are contorted and show repeated folds, while different beds are separated by hornblende-schist. Whether these latter are altered lava flows or intrusions is not clear; they do not possess amygdaloidal structures, and are sometimes coarsely crystalline and poor in felspar. An examination of the magnetic-quartzites, however, shows that the thinner layers gradually die out in the schist, and that the latter nowhere cuts the ironstone layers.

The similar magnetic quartzites around Zoet Vlei have been already described, but what is apparently the same horizon is found in the south-western portion of Uitspanberg, forming a narrow isoclinal fold in the granite. The rock in contact with the granite is usually thin magnetic quartzite, but sometimes a thin layer of hornblende granulite intervenes; next comes a considerable thickness of hornblende schist, then another thin ferruginous zone, followed by schist, while the centre of the syncline is formed by massive magnetic quartzites, giving rise

to black kopjes. Near the western boundary of Uitspanberg the magnetic rock contains actinolite or cummingtonite, but elsewhere the quartzites consist solely of granulitic quartz, with octahedra of magnetite and a small amount of haematite.

West of the Uitspanberg boundary, on Groot Witfontein, there is a prominent line of outcrops of the magnetic quartzites with a general N. 30° W. trend. The rocks are often finely banded, and show intense puckering about axes which dip steeply to the N.N.W. Actinolite schist traverses the rocks in bands parallel to the trend of the outcrops, without being puckered like the banded quartzites. The quartzitic rock occurs in three bands, the western one being the widest and nearly 300 feet thick, but in this case only the easternmost 80 feet or so contain sufficient magnetite to give the rock a dark colour. A belt of red sand separates this rock from a band of richly magnetic quartzite some 200 feet thick, in which the puckerings mentioned above are frequently seen. On the east this band is broken up by layers of actinolite schist; two other magnetic quartzite bands occur east of the schists, and the easternmost one includes much quartzite with little magnetite. A metamorphosed limestone intervenes between the easternmost belt and the gneiss. This rock (2171) is made of bunches of a mineral now represented by calcite, lying in a granular calcite matrix; parts of the mineral are still preserved, and seem to be a scapolite; the basal cross-jointing is marked by the same brownish substance that bounds the calcite pseudomorphs. The rock is considerably weathered and yellowish in colour; it is only occasionally seen in flat outcrops. Towards the south-east the magnetic rocks disappear gradually and the only rocks other than gneiss and vein quartz seen in a traverse across the strike are chlorite schists with bunches of actinolite in them.

About 2½ miles S.S.E. of Zwartkop Pan there is a ridge of magnetic quartzites, with some 200 feet of fine grained hornblende schist flanking it on the north-east side. In thin section (478) the quartzite is seen to consist of quartz in evenly bounded areas and magnetite, with a very little calcite. The magnetite occurs as grains or very small crystals arranged both in layers and scattered through the quartz, often entirely enclosed within the quartz individuals. A fissure lined with chalcedonic silica, evidently derived from opaline silica, traverses this slice. The quartz veins in these outcrops contain tourmaline.

On Klein Witfontein there is a band of quartzitic rocks about a mile long with N. 30° W. strike lying in the gneiss. They contain various amounts of magnetite, and on the eastern side are very rich in that mineral. This belt may have been a continuation of the belt on Groot Witfontein, though now separated from the latter by gneiss enclosing thin strips of hornblende— or actinolite-schist.

Between the long belt of magnetic-quartzites of Uitspanberg and the quartz-schists to the south-west are several little patches

of the former rock isolated in the granite. In the most south-easterly exposure the beds are invaded by a sheet of serpentine which, occurring in the centre of the exposure and cutting across the ironstones, separates them from the granite along a considerable part of the boundary. In the exposure nearest to the beacon on Vaalberg, the magnetic quartzites and hornblende schists are invaded by quite a variety of ultrabasic igneous rocks, from coarse hornblende-rock to serpentine; in some places the intrusion is so rich in magnetite that more than half the rock is composed of iron ore, the rest being tremolite. In other places the serpentine has been altered to a talc-schist. Granite veins are numerous in the hornblende-schist and ultrabasic rocks, and there is at many points an intermingling of acid and basic material, but no intrusion was found cutting across the magnetic quartzites, though here and there the granite is in contact with these beds of ironstone.

### *The Marydale—Stuurman's Puts Belt.*

On Brul Pan the Marydale beds come in between the granite and the Kaaien beds as a thin belt of hornblendic schistose rocks; they were traced continuously 16 miles to the south-east, where they apparently disappear in the granite of Wit Vley. From Brul Pan to the hill north-west of Stuurman's Puts they form a narrow belt rarely exceeding 300 yards in width, but on Stuurman's Puts they wrap round the end of the hills made of Kaaien beds and thicken to over 2 miles in width, probably owing to folding. A great variety of rocks make up this belt, but magnetic quartzites and augite-granulites are confined to the south-east end of it.

Where the road from Brakbosch Poort to Marydale passes through the eastern range of Kaaien hills the belt is about 300 feet wide, though it is not well exposed. The beds consist of thin slaty hornblendic rocks, more massive hornblendic schists with bands of amygdales, a bed with much calcite in it, and thin whitish quartzites. The gneiss from the eastern boundary of the beds breaks through them into the hornblende schists. One of the green cleaved rocks from this locality is seen in thin section (2141) to be a detrital rock with many quartz grains embedded in a fine grained matrix of chlorite, calcite, felspar, and magnetite. Two slices (2142, 2143) cut from the fine textured hornblende-schists, typical of the greater part of the 300 feet seen here, show short columns (apparently with prism faces occasionally) and grains of pale green actinolite arranged parallel to each other, set in a matrix of granular quartz and epidote and a little sphene. In one of the slices there are also some calcite and amygdales of quartz and epidote. No felspar was detected in the slices. These rocks are taken to be granulitised lavas of about the same composition as diabase. Another slice (2092) taken from an amygdaloidal band nearer Marydale shows very

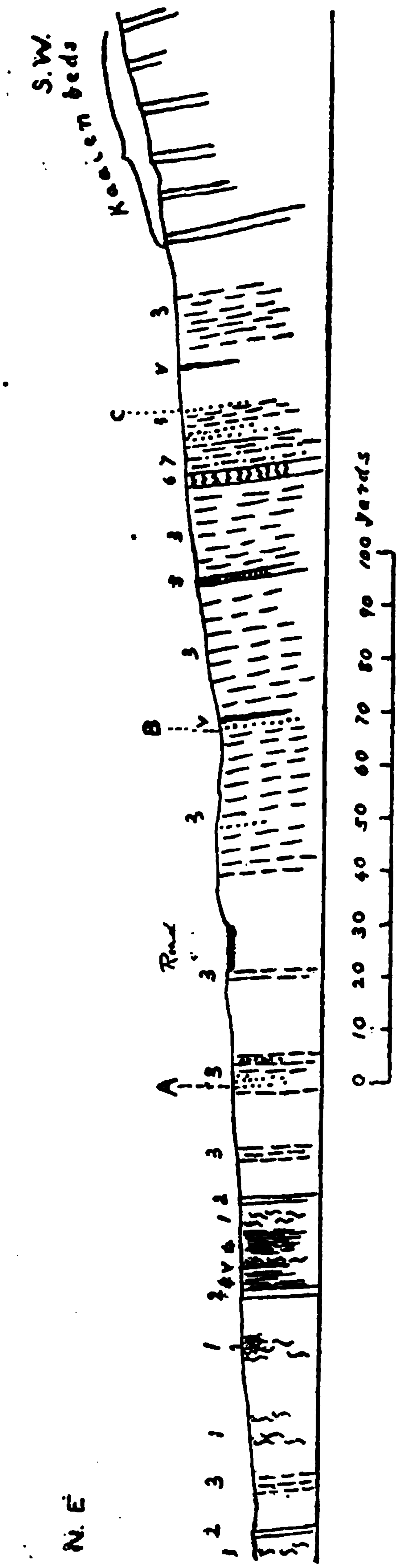



FIG. 4.—Section through Marydale beds S.E. of Marydale. 1, gneiss; 2, quartzite; 3, hornblende-schist, fine grained, with bands of amygdaloidal rock (dotted) in it; 4, mica-schist; 5, limestone; 6, felsite; 7, grey slates; V, vein quartz.

similar characters, a granulitic rock, with parallel structure given to it by the presence of numerous columns of pleochroic actinolite arranged in one direction. The lenticular areas, chiefly made of quartz and supposed to be amygdales, also contain zoisite and calcite.

South-east of Marydale the schist belt is exposed at many places, and a section measured across the strike at a place about two miles from the village, where the exposures are more frequent than usual, is given in Fig. 4. The section begins on the great area of gneissose granite on the north-east and ends in the Kaaien beds on the south-west. The rocks called hornblende schists are dark fissile rocks containing much actinolitic hornblende and several bands of amygdaloidal rock, in which the amygdales are mainly composed of quartz. A slice (2088) from the point A in the section shows more marked schistosity than those mentioned above from north-west of Marydale; the minerals are actinolite in elongated plates and short columns without definite faces, but not in grains; quartz in the form of a mosaic acting as groundmass to the actinolite; granular sphene; calcite and epidote in small quantities in the ground mass but more abundant in the elliptical areas taken to be amygdales; felspar is seen in some of the latter and so is a little strongly pleochroic brown biotite. There is a small amount of

magnetite. The supposed amygdales are made of larger grains than the rest of the rock, and are almost free from actinolite. A slice from B (2089) shows a finer grained rock containing less actinolite but more epidote than the one just described, and the granulitic structure is more marked on account of the small size and amount of elongated actinolite columns; no felspar, biotite, or iron ore was detected; there is a small amount of chlorite; the amygdales are frequent and are elliptical streaks of larger grains of epidote and quartz than occur in other parts of the slice; they also contain a little calcite and a few needles of actinolite; their boundaries are very sharply defined. A third slice (2092), from C, is very like (2088), but contains rather more actinolite and no felspar. The quartzites which form three thin bands in this section contain small amounts of sericite and muscovite, and are like the quartzites of the Kaaien beds to the south-west. The mica-schists are also like those in the Kaaien group. These rocks in the Marydale belt have not been examined under the microscope, but felspar is not noticeable in hand specimens. The beds called felsite in the section are pink and white banded rocks with occasional small porphyritic crystals of felspar and more rarely of quartz. In thin section (2091) it is seen to be made almost entirely of quartz and felspar with very small quantities of muscovite, sphene, and calcite; the groundmass has a micrognanitic structure, and the felspar, which is less refractive than quartz, is abundant; there are crystals of both striped and unstriped felspar, but the corners are rounded off and the faces are eaten into also; the plagioclase is albite, and the unstriped crystals are probably orthoclase. The felspars are not much altered chemically, though they are broken and traversed by very small veins of quartz mosaic and calcite. This rock is very different in appearance both from the gneissose granite outside the Marydale belt and the veins of it within this belt or other masses of Marydale beds in the district; it is probably a band of acid lava.

The limestone in the line of section is only about three feet thick, a grey rock weathering with a brownish crust. In thin section (2090) it is seen to consist of rather fine-grained calcite (probably dolomite also) and some chlorite; there are also a few isolated quartz grains, probably of detrital origin, and a very small quantity of iron ore. Another limestone, or possibly a continuation of the same bed, about half a mile further south-east contains much iron, and weathers with a thick yellow crust; a thin section (2089) shows a rather coarse-grained crystalline limestone with much haematite in dendritic growths throughout. An interesting feature in this rock is the presence of several groups of concentrically arranged dusty inclusions, which are evidently the remnants of oolitic structure. In a few cases a radial structure is discernible in the calcite between crossed Nicols, but usually each group of particles lies entirely within one individual of calcite. The limestones make few out-

crops, and they were not noticed again to the south-east, though they are very conspicuous on Blaauw Puts to the north-west. The slaty rocks which lie between the felsite and the higher hornblende-schists are of a kind rarely met with in this group; they are grey in colour, while the rest of the thinly cleaved beds are green with hornblende, chlorite, or epidote.

Near Stuurman's Pūts the belt widens out, and a thicker band of quartzite intervenes between the gneiss to the north-east and the dark granulites and schists; another feature is the presence of fine-grained grey granulites within the belt. These are banded rocks, and the bands are often sharply contorted, as is the case also with the darker coloured granulites. The grey granulites make up an important part of the Marydale beds on Stuurman's Puts, and in the country to the south-east, and again in the Kaaien beds of the Brakbosch Poort hills; but they have not been observed at Marydale or Zwartkop. In composition they must be like the gneiss and granite but there is generally much more magnetite or ilmenite in them. Garnet is also a usual constituent, but this mineral is often seen in the Prieska gneiss, etc. These granulites are connected with the quartzites by rocks which have less and less felspar in them; some rocks collected in the field as quartzites prove to be felspathic granulites, and others taken to be grey granulites contain but little felspar. The felspar is the chief variable constituent, micas and iron ores, etc., are found in both quartzites and typical granulites in varying amounts. Some of these rocks must certainly be looked upon as quartzites with felspar in them, either developed from material in the quartzite originally or introduced from the granite magma during intrusion, and it was found impossible to draw the line between such rocks and those which have the mineral composition of granites, though not their structure. A slice from one of the grey granulites of Stuurman's Puts (2184) contains quartz, striped and unstriped felspar, of which the refraction is less than that of quartz, brownish red mica, magnetite and garnet. The structure is typically granulitic, though the mica forms flakes of smaller size than the quartz and falspar grains when seen in vertical sections. The garnets are in grains without crystal faces.

The hornblende-schists of this neighbourhood have many bands of amygdaloidal rock in them. A section through one of these (2185) shows a matrix of hornblende, pyroxene, felspar, probably also quartz, sphene, and a little calcite containing clear oval areas of quartz, felspar, and a little epidote, garnet, hornblende, magnetite, and pyrites. The hornblende in the matrix is a strongly pleochroic green-yellow variety and forms both small and large irregularly shaped masses, which rarely include the other constituents; the same mineral occurs in the supposed amygdales. The pyroxene is the bluish variety of augite so abundant in the basic granulites of the Prieska district; it forms large masses without crystal faces, and encloses

much hornblende and felspar. The felspar is in small interlocking areas, and seems to be a basic kind, for its surface shows considerable relief; it is twinned, but irregularly. The presence of quartz in the matrix is doubtful, but it is plentiful in the amygdales. From other slices in the dark hornblendic rocks near Stuurman's Puts house (509-514), it is evident that the rocks, which have a similar appearance in hand specimens, differ in various ways; the chief points are that as the felspar decreases in amount the epidote and zoisite increase; the green hornblende described above is replaced by two varieties, one in which the pleochroism is X deep green, Y greenish yellow, Z blue, and another in which these colours are tinged with brown; the amount of quartz present varies considerably; in structure there are gradations from the schists in which the hornblende occurs as ragged plates and greatly elongated prismatic columns though without faces, to the granulites, in which the hornblende occurs as grains, occasionally elongated, but usually of about the same dimensions as the quartz and felspar, and the outlines of all the grains are smooth and without the jagged character seen in the schists.

Some peculiar rocks of a pale grey colour, with irregular black patches, are interbedded with the amygdaloidal hornblende schists north-west of Stuurman's Puts house. In thin section (2186) the pale portions of one of these is seen to be a granulitic mixture of quartz, felspar, and epidote, and the black patches aggregated grains of blue-green hornblende enclosing grains of quartz, felspar, and epidote. Towards the south-east end of this belt there are thin bands of magnetic quartzite lying in the green schists or between them and the gneiss to the north-east. These quartzites are very heavy and finely banded rocks. A thin section (2181) shows a granulitic structure of quartz, magnetite and a colourless mineral with a cleavage and extinction angles up to 23° on it; in the occasional transverse sections two cleavages are inclined like those of amphiboles; the double refraction is rather high; it is slightly altered to a greenish substance round the edges and along cracks. This mineral is the same as the amphibole in some of the Kraaipan magnetic quartzites described in the last Annual Report, p. 136, and said possibly to be cummingtonite. There are a few grains of apatite in this rock. The magnetite often has crystal faces. In this portion of the belt there is a great thickness of a very fine-grained dark green rock (2180 is cut from it), made of green hornblende, quartz, felspar, magnetite, and garnet, of which hornblende is by far the most abundant; the garnets occasionally have idiomorphic outlines and are much larger than the other constituents, but the mass of the rock has a very fine-grained granulitic structure. Along part of the contact of this rock and the gneiss to the north-east there is a remarkable rock with a groundmass of minute pale hornblende grains and a little magnetite, but without quartz or felspar (2179) and containing

large imperfect crystals of a chlorite which is colourless in thin section but black in the hand specimens. The chlorite is repeatedly twinned along the base; it includes many hornblende grains. The layer with the chlorite crystals is only a few inches thick, and is in contact with the gneiss. Within the fine-grained hornblende rock described above there is a thick band of garnetiferous hornblende granite (2182); the hornblende is a greenish-blue variety, and quartz and magnetite are the next most abundant minerals; felspar is only seen bordering the garnet. The rock, though it has pronounced granulitic structure, is distinctly foliated owing to the tendency of the magnetite and quartz grains to occur in layers one grain thick; this parallel structure is carried on through the large crystals of garnet, though the layers immediately surrounding the crystals are bent, so as to give the crystals the appearance of the "augen" in augen-gneiss. The garnet is very pale pink in thin sections and encloses grains of all the minerals found in the matrix, except felspar, but only a few grains of augite are found in the garnet.

One of the bands of schist contains tremolite and actinolite in about equal quantity in the form of grains and short columns, some of which (tremolite) show prism and pinacoid faces; there are also quartz, felspar and magnetite. In some cases single individuals are made of the two varieties of amphibole.

West of the high quartzite hill near Stuurman's Puts house and from two to three miles distance from it there are two long ridges of dark rock with porphyritic felspars and amygdales in bands. The peculiar characters of these outcrops were only noticed when thin sections from one of them were examined, so the relations of the two varieties collected are not known, except that the one kind fringes the other without the intervention of a third. They are certainly to be regarded as detached masses of the Marydale beds. One of the rocks cut (2188) is a rather fine-grained schistose rock with small rounded crystals of felspar and slightly pleochroic hypersthene in a groundmass of green hornblende, felspar, possibly also quartz, a little magnetite, sphene and augite. The groundmass is very fine grained and granular, but the hornblende, a rather dark green variety like some of the hornblende in the granulites, tends to form larger grains. The felspar (andesine-labradorite) crystals are distorted and often broken, granulitic felspar and hornblende occupy the cracks. The hypersthene is partly changed into green hornblende, especially along the borders, but there are some hornblendes which evidently represent whole hypersthene crystals, for they are crowded with the little inclusions elsewhere seen only in the latter. Epidote and garnet were not seen. The second slice cut (2187) came from the eastern edge of the band and near the gneiss surrounding it. In the hand specimen there are rounded felspar crystals up to half an inch in length embedded in a hornfels-like matrix. Under the microscope the

matrix is seen to consist of a fine-grained mixture of quartz, brown biotite, possibly felspar, dark green hornblende, blue augite, magnetite, and innumerable minute garnet crystals which often lie wholly within the slice. The hornblende and augite form larger patches than the other constituents, and they are not distributed uniformly through the rock, but in small groups. The clear areas are either rounded crystals of an acid plagioclase, which often enclose flakes of biotite, hornblende, augite and magnetite, but never garnet or quartz; or they are wholly or partly patches of quartz mosaic; in the latter case the quartz surrounds a kernel of felspar or occupies half an area, while felspar fills the rest of it. There are a few rather large crystals of zircon with well marked zonal structure.

On the south-west side of Stuurman's Puts the gneiss seems to lie up against the Kaaien beds for several miles, but near the southern beacon the granulites appear again in a thin belt, in which there are also quartzites and quartz-schists, between the Kaaien beds and the gneiss. No amygdaloidal rock was seen here, and the granulites in general are less hornblendic than those to the north. Hand specimens may be obtained showing a sharp limit between the rocks called quartzites and the granulites; the former have characteristically bright fractured surfaces, while those of the latter are duller, and the weathered surface of the quartzite is grey and stands out well from the dull almost black surface of the granulite. A slice (2189) through such a junction has been cut, but the distinction between the two rocks is much less obvious than in the hand specimen; the quartzite is made of quartz, with a few grains of felspar, garnet, greenish hornblende, epidote and magnetite; the granulite is finer in grain and consists of much quartz, with some felspar, blue-green hornblende, blue augite, epidote, magnetite, garnet and sphene. The coloured constituents are more abundant in the granulite. A thin quartzite, green in colour, in this granulite belt is made of quartz and epidote (2190), with very little garnet and sphene. The grains are flattened in one direction, which gives a parallel structure to the rock, and the epidote also occurs in strings of grains.

From this locality south-eastwards nothing corresponding to the Marydale beds was met with at the junction of the Kaaien beds and the granite for many miles; but there are detached areas of them in the gneiss of Wyngard's Pan, Wit Vley, Spioen Kop and Blaauwbosch Poortje, some of which will be described below. Various granulites are again seen flanking the Kaaien beds of the north of Bosjesman's Berg and the west of Jackal's Water; they are hornblende-schists, grey banded granulites and mica schists dipping south-westwards at high angles. A thin section (2209) from a dark grey rock on the north-eastern side of Jackal's Water shows a granulitic mixture of quartz, green hornblende, epidote and zoisite, a very little cloudy felspar, granules of sphene and small crystals of rutile. The horn-

blende forms the largest grains, and some of them show one or more crystal faces; the larger individuals enclose grains of quartz and epidote and crystals of rutile; the epidote encloses quartz and rutile. The felspar is in small quantity and clouded with alteration products; epidote is abundant in these patches.

On Blaauw Puts (part of Kaboom) the Marydale beds come in again between the Kaaien beds and the gneiss for about two miles, when they disappear under sand. There are limestones and amygdaloidal hornblende-schists dipping westwards under the Kaaien beds of the hills. The limestones are remarkably like those of the Campbell Rand group, though they cannot be more than 500 feet thick. They include bands of dark chert, and are thicker than any found elsewhere in the Marydale beds. The greater part of the hornblende-schists lies above the limestones but they also occur interbedded with them, and at one place were seen below the limestone, between the latter and the granitic gneiss. For over 200 yards at least the granite and limestone are in contact, and veins of granite penetrate the limestone. The contact is exposed in a prospecting pit. A thin section of a piece of limestone (2118) from near the contact consists chiefly of rather coarse-grained calcite, with a fair amount of quartz and some plagioclase, deeply pleochroic brown biotite, muscovite, colourless garnet and some tourmaline. A section from the granite near the contact (2119) contains almost as much calcite as granitic material; the granite is made of plagioclase, quartz, brown mica (chloritised) and muscovite; there is a considerable amount of colourless garnet. The granite vein in the limestone (2120) has been much shattered by movements subsequent to its consolidation; it is made of fragments of quartz and plagioclase set in a fine-grained base, which contains much chlorite and a little epidote.

On the farm Luis Draai there is a strip of hornblendic rock near the north-west foot of Ezel Rand, stretching for nearly two miles along the strike of the Kaaien beds, but in part covered by a Dwyka outlier and elsewhere obscured by superficial deposits. Some quartz-schists of the Kaaien type lie between them and the Matsap beds, but whether there is a reversed anticline along the axis of which the hornblende rocks lie, or whether they are interbedded with the Kaaien beds is not certain, though in one place the latter were seen wrapping round the south-west end of a large mass of the hornblende-schist. In thin section (2112, 2113, 2114) the rocks are seen to be almost entirely made of alteration minerals, tremolite, actinolite, chlorite, epidote, quartz and iron ores, but in (2114) the remains of plagioclase can be made out, looking like altered felspar in a holocrystalline diabase.

South of Jackal's Water this belt of granulites cannot be followed with certainty, though at the foot of the ridge of Kaaien

beds a black hornblende schist crops out at a number of points on Uitzigt, and forms a zone 250 feet in width not far from the pan on Modder Fontein. The rock is very coarse in the centre and on the east, and probably represents a basic intrusion. A thin section (693) shows long prisms of green hornblende sometimes with irregular boundaries, full of little inclusions of quartz and felspar, the groundmass being a granulitic mixture of the two latter minerals.

## Isolated Occurrences in the Gneiss.

One of the most puzzling groups of outcrops entirely surrounded by granitic gneiss, is found on the eastern part of Brakbosch Poort; it was seen in 1899 and put down as a mass of intrusive diabase with amygdales in it, a second visit this year showed that the dark rocks, which crop out over an area about 300 yards long by 80 wide, are traversed by veins of coarse muscovite-granite. In the hand specimens the rocks are very much alike; they resemble Karroo dolerites, and are without trace of schistosity; the amygdales are of quartz, and are as much as half an inch long; porphyritic plagioclase is occasionally seen. Seven thin sections were cut from different parts of the outcrops, and they revealed unexpected features that have been met with in no rocks of the Marydale group; they fall into two groups, augite-labradorite rocks and actinolite-labradorite rocks, though there is evidence of an intermediate type. The augite-labradorite rocks (2137, 587, 588, 589, 590) have a great resemblance to some dolerites of the Karroo type, though there are important points of difference; the hand-specimens contain a few quartz amygdales, though not so many as the collected specimens of actinolite-labradorite rocks; as the difference between the two was first noticed when the thin sections were examined, it cannot be said that the amygdales are generally more abundant in the actinolite rocks. Under the microscope the chief constituents are seen to be labradorite and colourless augite, the next most abundant are olivine and hypersthene, then iron ores and strongly pleochoric red biotite, and small quantities of pleonaste, and serpentine and actinolite as alteration products of the olivine and pyroxenes respectively. The structure is typically ophitic; augite, together with hypersthene grown on to it, form large masses partly or even completely enclosing labradorite; on the other hand, the large crystals of labradorite include straggling patches of both augite and hypersthene, as well as other minerals, arranged in zones roughly parallel to the boundary of the felspar whether a crystal face or not. The felspar is often crowded with very minute black dots, which give a cloudy appearance to it, but are only just visible under an eighth-inch objective. The augite often encloses black

rod-like bodies, much longer than the similar things which give the hypersthene a dusty appearance; in addition to forming growths on augite, hypersthene often occurs intergrown with that mineral. Both kinds of pyroxene are in places altered to pale green fibrous hornblende; in some slices this process has gone further than in others, and these form a link between the two classes of rock. The olivine is in irregularly-shaped grains which are cracked; serpentine occurs in these cracks; the olivine is surrounded either by one of the pyroxenes or felspar, in the latter case there is always a zone of fibrous material between the two, usually a double zone, the layer next to the olivine being colourless, and that outside it green; the fibrous material seems to be amphibole. The red biotite is just like the biotite so often seen in the Karroo dolerites. Parts of section (589) have the characters described above, but in other portions the pyroxenes have been entirely or partially altered to slightly pleochroic green amphibole, which is mostly fibrous, but in places uniformly developed without fibres over considerable areas. In many places pieces of the pyroxenes are still left. Both the hypersthene and augite are thus altered. The labradorite remains quite fresh, and therefore, of course, the ophitic structure is preserved. In the altered parts of the slice the olivine shows more or less complete change to fibrous aggregates, which are not serpentine, but are like amphiboles in their polarisation tints and extinction angles. The irregular clusters of magnetite grains remain in the alteration products. The red biotite in the same areas become partially bleached or altered to pale greenish fibres.

Two slices cut from the actinolite-labradorite rock show progressive stages towards the complete obliteration of the structure described above. One of these (2138) is made of labradorite, pale actinolite in most of which pleochroism is scarcely seen in thin section, though small portions are distinctly pleochroic, and a very little sphene and magnetite. There is no olivine or red biotite, nor are there any patches which certainly represent those minerals. The ophitic structure is very obvious in ordinary light, though, owing to the various positions of the actinolite fibres and plates replacing augite, it is obscured between crossed Nicols. A very interesting point is that the actinolite does not occupy only the space where the augite was, but its jagged ends project into the labradorite; in parts of the slice this has gone on to such an extent that the ophitic structure is obliterated. Actinolite makes its appearance within the labradorite also. In these much changed parts there is always a small amount of granulitic quartz. In slice (2136) the ophitic structure has been so obscured that it would not have been recognised without the aid of the intermediate stages described above. Actinolite and labradorite are the chief constituents, but there is more granular quartz than in

(2138), and some sphene, magnetite, and chlorite are present. The felspars, though quite fresh, are very much broken up by streaks and patches of actinolite, and the latter mineral forms much larger uniformly developed plates than in the slices described above. There can be no doubt that we have an ophitic dolerite which has been partly changed into actinolite schist, nor is there any doubt that the outcrops are penetrated by the granite. The remarkable thing is to find a rock older than the granite retaining its original structure so well as in some of the specimens described. Whether the dolerite was originally an intrusion, as its micro-structure suggests, is of course unknown.

There are several occurrences of basic rocks, which show distinct relationship to the augite-labradorite rock of Brackbosch Poort. From their appearance they were regarded in the field as basic representatives of the Karroo dolerite group, and in last year's Report, p. 88, one of these rocks, forming a dyke (augite-picrite) in the Kheis (Kaaien) beds on Tsebe, is described as a member of the Karroo group of intrusions, in spite of the fact that such basic varieties had not been seen cutting the Karroo formation. This fact might easily be explained by the similarity of the picrite outcrops to the ordinary olivine-dolerite, so that the differences might be overlooked in a region where the ordinary dolerite is abundant, and where the acid varieties, if present, would at once attract attention. Until definite evidence is obtained, either from intrusions in the Karroo formation on the occurrence of boulders of these picrites, etc., in the Dwyka, the question cannot be regarded as settled for the whole group, and here it will be convenient to describe the rocks concerned under this section of the Report.

On Wit Vley, Lot A, outcrops of a heavy black rock, distinctly holocrystalline, were found in 1899 near the Stuurman's Puts boundary. Under the microscope (493, 494) they are seen to be made of labradorite or bytownite, augite, olivine, a very little enstatite, iron ores and actinolitic hornblende. The structure is ophitic, though felspar is present in too great amount to allow it to be conspicuous. The felspar and augite have numerous inclusions like those in the same materials in the Brakbosch Poort rock. The felspars are twinned both on albite and pericline plans. The olivine is surrounded by zones of alteration or interaction products where lying in felspar. The enstatite is not pleochroic. There is no red mica visible. The actinolite is evidently an alteration product, though from which mineral it is chiefly derived is not clear. This rock is an olivine-gabbro.

Another outcrop of a similar looking rock was found near the boundary of Lot A and Lot B, south of the above-

mentioned rocks, also surrounded by gneiss. In thin section (2191) it is seen to differ considerably from the rocks above described, and to be an enstatite-picrite or olivine-norite. It is made of olivine, enstatite, augite, felspar, brownish biotite, alteration products and iron ores. The felspar is present in rather small amount, and is much altered, the central parts being so crowded with a brown substance as to be opaque. The enstatite is very plentiful and sometimes shows crystal outlines.

On Jackals Water, about a mile N.W. from Water Kop, there is a group of dark outcrops 40 yards long by 10 or less wide in the gneiss. A thin section (2211) shows that this rock is a hornblende-augite-picrite made of olivine, augite, hornblende, red biotite, felspar and iron ores. The olivine has much dendritic magnetite in it, and often forms idiomorphic crystals, as the augite does too. The hornblende is a brown variety, very rarely seen in the Prieska district, and it is in places grown on to augite; it encloses grains of the other minerals except felspar. The biotite often encloses other minerals. The felspar is not abundant, and it encloses crystals of olivine, mica and augite.

On Greeff's Puts (eastern part of Rietfontein, Lot A) two lines (N.N.W.) of large black boulders lie in the granite area some two miles east of the granite and Ventersdorp junction. They evidently mark the position of elongated bodies of the rock. A section through one of them (2100) shows that it is a hornblende-augite-picrite rather like the Jackals Water rock, but the augite has a distinctly brownish colour in thin section. The other minerals and the structure are like those in the Jackals Water rock.

On Keuk en Draai two similar looking masses of rock were found in the Kaaien beds lying parallel to the strike of the latter. One of them has been cut (2,122), and is seen under the microscope to be a hornblende-augite-picrite like the Greeff's Puts rock. In the specimen taken there is a large mass of augite enclosing much olivine (grains and crystals), biotite and magnetite. In other parts of the slice augite crystals lie in felspar.

The rocks from Keuk en Draai, Greeff's Puts and Jackals Water are very like the Tsebe dyke, though in the latter the brown hornblende is present in such small quantity in the one slice prepared that it escaped notice last year (Report for 1907, p. 88), probably having been confused with the biotite, but on looking for it the mineral is found as a narrow fringe on one of the augite plates.

These rocks may perhaps be pre-granitic intrusions, but of post-Kheis age. The fact that they have undergone so little alteration, if this supposition as to their age proves to be correct, is remarkable, but analogous cases have been established in the north-west of Scotland, where ultra-basic and

basic dykes of pre-Torridonian age have in places escaped alteration.[1]

On the right bank of the river bed, between Marydale and Draghoender, there is a very well exposed group of outcrops showing junctions of gneissose granite with quartzite and hornblende-schist. The hornblende-schist is a very dark rock, which resembles closely many hornblende-schists in the district, but no section has been cut from it; it is distinctly schistose. The gneissose granite varies considerably in appearance according to the development of the parallel structure; it is mainly a quartz-felspar-biotite rock, though sericitic mica

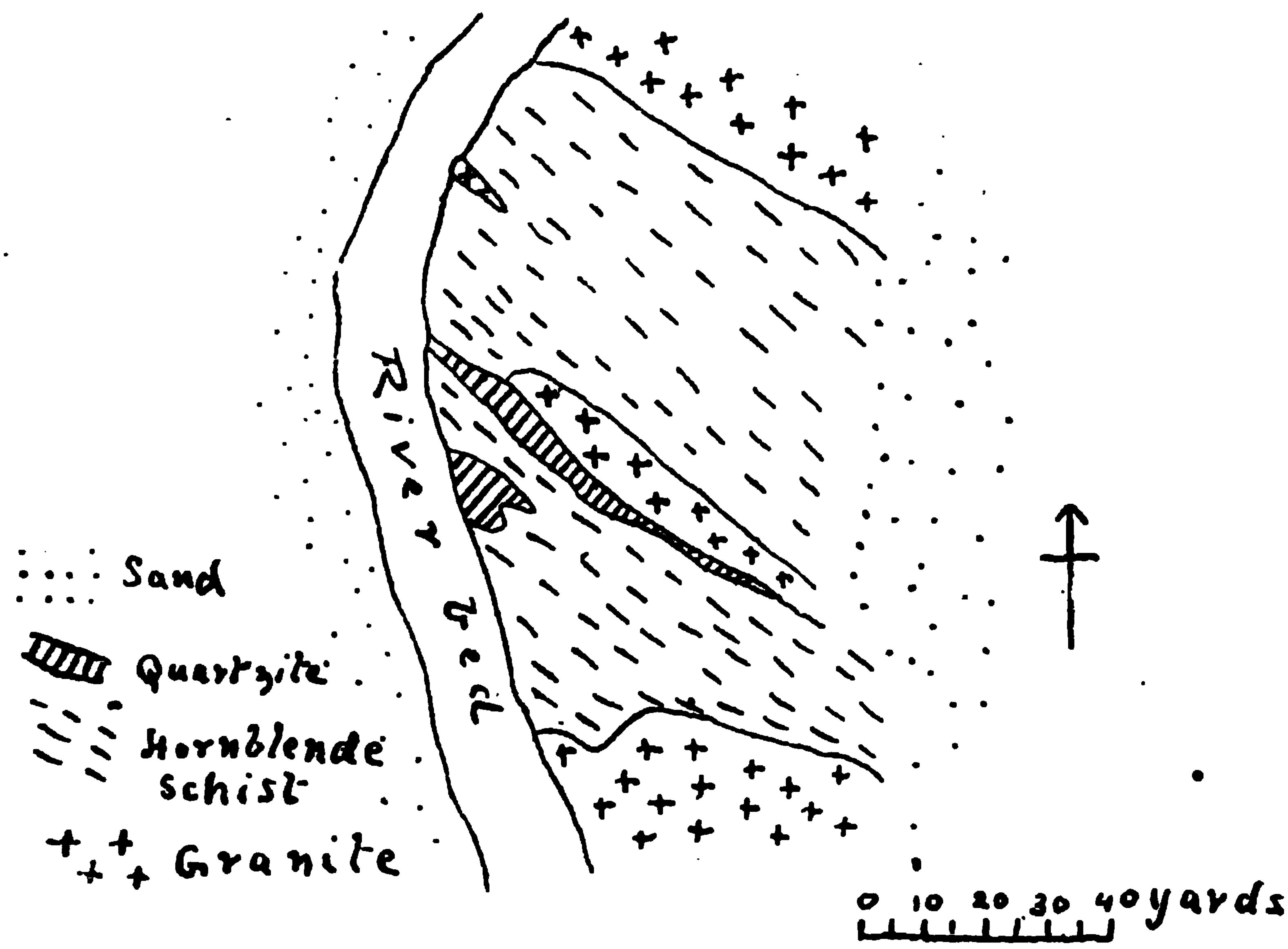



FIG. 5.—Plan of outcrops on right bank of river bed above Draghoender.

is developed along some planes. The quartzite is sericitic in places, but does not become a mica-schist; in thin section (2099) it is seen to consist almost entirely of quartz with interlocking suture-like junctions between neighbouring grains, and it shows strain shadows. There are small greenish-brown biotite flakes and a very little calcite. The mica is often completely enclosed by quartz. The original nature of the hornblende schist in this case is not clear, it has no altered amygdales in it and may have been intrusive in the quartzite group, which can be assigned to the Kheis series. The granite is certainly intrusive in both quartzite and hornblende schist.

[1] The Geological Structure of the North-West Highlands of Scotland, Chap. VII. Several points of resemblance to the Scotch rocks were noticed in those of Prieska; e.g., the felspar, with its dusty inclusious, shown in Pl. XLVII., fig. 2, of the Memoir is just like the felspar in the Brakbosch Poort rock.

## Zwart Kop.

The prominent hill, known as Zwart Kop, rises about 300 feet from the plain, and owes its existence to a band of magnetic quartzite traversing it with N. 10° W. strike. All the beds in the area dip at high angles towards the West or W. 10° S. (See Figs. 6 and 7.)

On the slopes to the west of the ridge the granite contact is

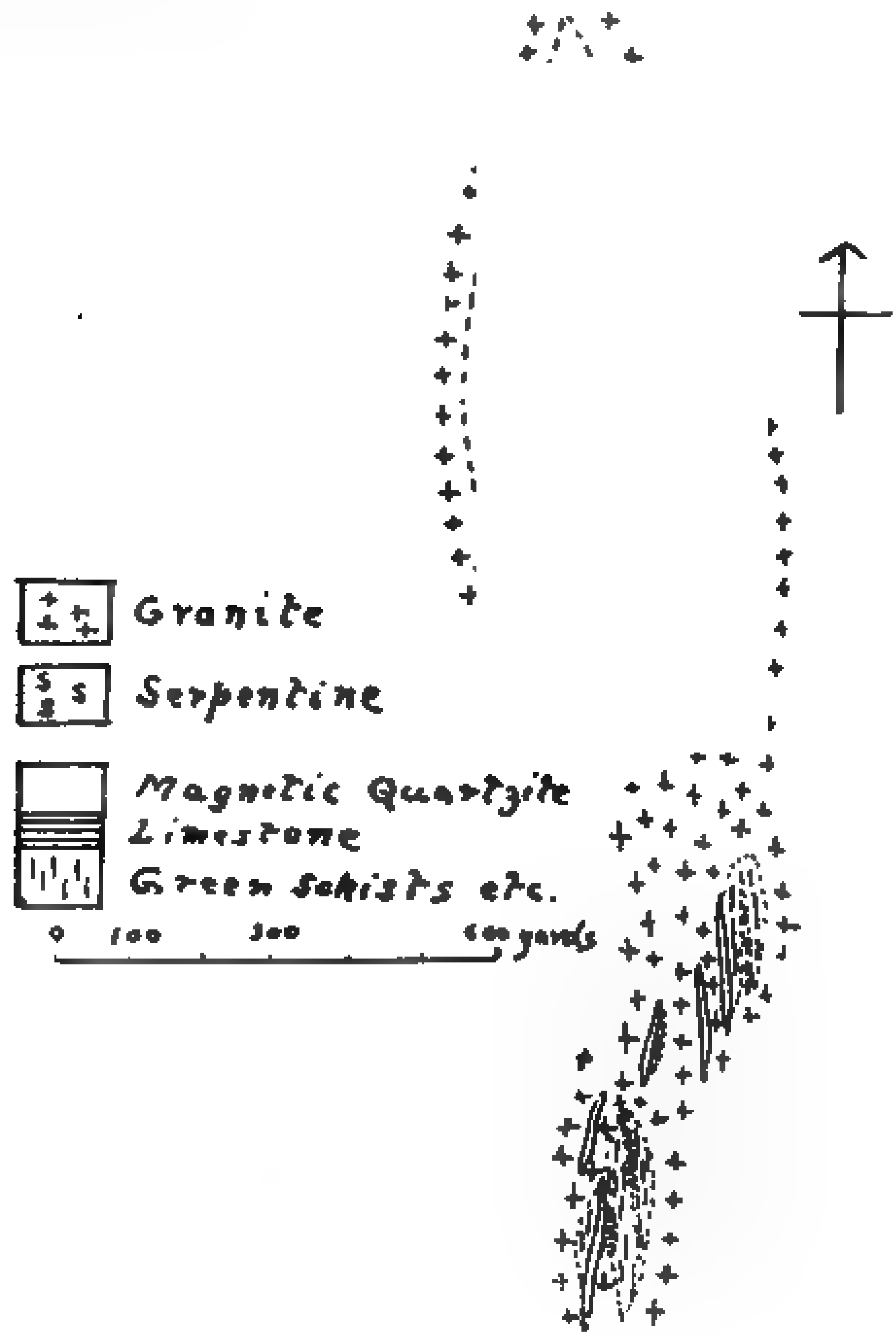



Fig. 6. Plan of Zwart Kop. The area of magnetic quartzites in the northern outcrops includes hornblende-schists and granite veins.

concealed, the first older rocks seen are green schists. In many places amygdaloidal structure is seen, though the amygdales are considerably pulled out and flattened along the planes of schistosity; thin slices (2058-2060) cut from amygdaloidal portions of the schist show traces of the original structure in having lath-shaped crystals of andesine still preserved, as well as the flattened quartz-epidote amygdales. The ground

mass is usually a mixture of green actinolite or colourless tremolite, quartz, sericite, calcite, chlorite, and magnetite, and granular sphene; the hornblendic minerals are usually in shreds, but occasionally rather large uniform plates occur; the quartz and epidote tend to have granulitic structure. A section through a greenish-blue-schist (2067), from the southernmost patch of these rocks shown in Fig. 6 consists of quartz, chlorite, actinolite, epidote, chlorite, magnetite and leucoxene; there is apparently no felspar. No definite structure, except a rough schistose arrangement of the minerals, is visible.

A very interesting rock (2070) came from the green schist adhering to the eastern side of the third mass of magnetic quartzite from the south end of the outcrops shown in Fig. 6. It is an epidote-hornblende-quartz granulite with some of the grains elongated or flattened in one plane, and it is a connecting link between the schistose lava described above, and the basic granulites so abundant further south. The minerals form grains which are of a fairly uniform size, but some of the hornblende grains, a strongly pleochroic bluish green variety, are longer than any of the others; they have a very different appearance from the ragged plates and fibres of actinolite, etc., in the lava described above. The hornblende does not always have the same colour throughout each grain. The great characteristic of this rock, as of all those termed granulites in this Report, is that the grains are comparatively smooth and do not have the sharp and jagged outlines seen in schists and many partly altered lavas, such as epidiorites. The epidote is almost or quite colourless; there seems to be no felspar; several grains which looked as though they might be clear felspar proved to be uniaxial. There is a small amount of magnetite and sphene. There are some clear elongated areas of quartz which may represent amygdales; the grains in such areas are larger on the average than those in the matrix.

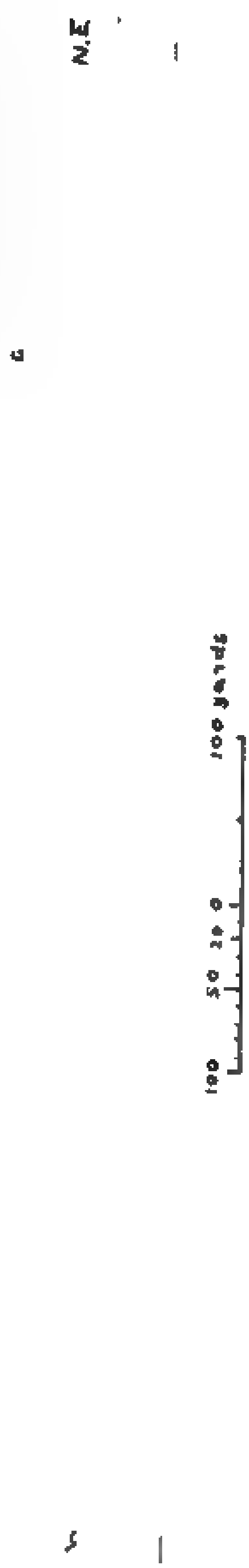



FIG. 7.—Section through Zwart Kop south of the beacon. G, granite; S, serpentine; 1, magnetic quartzites; 2, green schists with bands of amygdaloidal rock; 3, limestones; 4, chert; 5, arkose; V.Q., vein quartz.

The green schists lying amongst the thick magnetic quartzites of the ridge are rich in green hornblende. A section through one of these (570) proves it to be made of strongly pleochroic green hornblende in irregularly shaped areas of very different sizes; some are needles and others large plates; there is often a narrow edge of paler hornblende bordering the darker interior of a grain; much felspar, which is rarely twinned, occurs in jagged areas containing flakes of hornblende and grains of epidote; there is little quartz, and a fair amount of iron ores, in many cases surrounded by sphene or some related mineral. This schistose hornblende rock certainly had a different origin from that of the altered lavas to the west; it breaks across the magnetic quartzite bands, though clear veins of it were not found. In a mass of rocks which has been so much sheared as that of Zwart Kop, the abrupt cutting off of a hard quartzite by a schist may be due to mechanical disturbance after the schist was there; on the other hand the schist may be an intrusive rock. Both this schist and other rocks in Zwartkop are penetrated along their strike or schistose planes by thin sheets of granite.

Two bands of limestone, separated by green schistose slates, were traced for some 500 yards on the west slope of the ridge. They are grey or yellowish in colour, and weather with the usual rough surface peculiar to calcareous rocks. In thin section (2062, 2063) cherty silica and chlorite, as well as a small amount of magnetite, are seen to be present in addition to the carbonate, which is in very irregular areas with jagged edges. Other thinner bands of limestone were seen on the same slope, and small patches were found amongst the magnetic quartzites and hornblende schist on the top of the ridge, and again in the southernmost group of outcrops. Granite crops out within a few inches of a limestone[1] on the top of the ridge, though a slice from the latter (2078) shows no features that are not found in the slices described above. Near the westernmost band of limestone there is a bed of grey schist two feet thick, though it does not seem to extend far. Under the microscope (2061) this rock is seen to be made of quartz or some other anisotropic form of silica in minute areas, and specks of carbonates are scattered through it; there are veins and patches of larger individuals of quartz traversing the rock, and also some magnetite. The rock may, perhaps, be a portion of the limestone which has undergone silicification.

A rock taken in the field to be an arkose, or quartz-felspar grit, forms a layer about a foot thick in the green slates on the western side of the top of the ridge. It is only exposed for a few feet at a time, but was seen at intervals along some

---

[1] Contains 32·9 % of $CaCO_3$ and 24·7 % $MgCO_3$; analysis by Prof. B. St. J van der Riet.

200 yards. The appearance of the rock is so different from that of granite veins, recognised a short distance away, that it is difficult to look upon it as a granite intrusion crushed in place. In thin section (2066) there are large grains of albite, partly decomposed, with irregular but not definitely rounded outlines, set in a fine-grained matrix consisting largely of quartz-mosaic with dusty matter and chlorite flakes.

The magnetic quartzites form two thick bands with a thinner one between them in parts of the crest of the ridge. They stand out so prominently, and fragments from them cover the surface so thickly that it is difficult to follow the outcrops of hornblendic rock and granite, which are occasionally seen. The magnetic quartzites also occur in short thin beds amongst the green schists west of the main ridge, and in five larger masses in the southern groups of outcrops, which are separated from the northern by granite. These quartzites contain varying amounts of magnetite, but they have not been examined in a detailed way. They resemble the rocks described on p.p. 31, 37.

On the eastern slopes of the ridge a thin band of hornblendic schist separates the magnetic quartzites from a belt of green serpentine containing veins of chrysotile and penetrated by thin dykes of granite. Many slices have been cut from this serpentine without yielding any definite information as to its origin. The rock consists almost entirely of flakes of serpentine, with varying but small amounts of carbonates and dusty iron ore between them. The flakes sometimes make feathery aggregates, and in other cases they are arranged in two groups nearly perpendicular to each other. The disposition of the dusty iron ore rarely gives any indication of the shape of any former constituent; in one case, however, the grains outline variously-shaped small areas of serpentine, but though some of them may be sections through orthorhombic crystals, they do not resemble pseudomorphs after olivine. Two slices (564, 565) show a peculiar serpentine, or hydrated magnesian silicate with low double refraction and peculiar pleochroism in tints of dirty brown; under a high power these colours are seen to be due not to the colour of the serpentine itself but to the very minute inclusions in it. The mineral itself is colourless, and in form of spindle-shaped or stout columns; the brown pleochroic inclusions are either distributed throughout it, or confined to the inner part, or, again, the peripheral part of a column; they are arranged so that the deepest tints are seen when the short diagonal is parallel to the length of the column, which is also the direction of greatest elasticity, so the mineral is negative, like antigorite. The interference colours of the serpentine are peculiar brownish greys, but there are also bunches of fibres, always free from the brown inclusions, which give the blue tint seen in the other serpentines of

this locality. There are in these slices grains of a mineral with high refraction, but very low interference colours; it is uniaxial and probably idocrase.

This band of serpentine is certainly older than the granite, which sends veins through it, but whether it was an intrusion in the Marydale beds or an altered volcanic or sedimentary rock is unknown. Thin veins of chrysotile occur in it.

Veins of quartz occur in various parts of the green schistose rocks, but they do not seem to mark the position of any important junctions.

Granite forms many thin dykes or veins running parallel to the schistose planes, both in green schists of the west side of the hill and in the hornblende-schist between the magnetic quartzites of the crest of the ridge, and again in the green schists of the southern outcrops, also in the serpentine. On the south-west side of the northern mass the green schists abut against granite, whether this is an intrusive contact or a fault is uncertain. The shape of the whole mass reminds one of that of the numerous inclusions of green schists scattered through the granite of Prieska, though the latter are usually on a much smaller scale.

Amongst the green schists are a few thin bands of a different type of green rock from those described above, though made of the same minerals (2065), felspar near andesine, two kinds of hornblende, one pale green and the other, in much smaller quantity, deep green, epidote, chlorite, little quartz, leucoxene and sphene. This rock is evidently an altered dyke or sill.

To the south-south-east of Zwart Kop, and some 2½ miles from it, there is a low hill with much vein quartz scattered along it; the quartz fragments come from a vein lying on the south-east side of a band of magnetite-quartzite and hornblende-schist about 500 yards long and 120 wide, striking N. 15° E. at the northern end, and N. 10° W. further south. There are many veins of granite along foliation planes in the hornblende-schist. The magnetite-quartzite is on the western side of the band, and is like the Zwart Kop rock; the hornblende-schist is also like the schist on Zwart Kop ridge, but no amygdaloidal varieties were seen here. The band is surrounded by granite.

Between this hill and Zwart Kop there are short bands of diabase passing into markedly schistose rocks and entirely surrounded by granite. One of these, about 300 yards south of Zwart Kop, was traced through 400 yards at intervals; it is distinctly amygdaloidal in places. A thin section (2057) shows it to be made of tremolite and very pale actinolite, epidote, zoisite, quartz, and some remnants of felspar and granular sphene. The constituents are very small, and have a parallel arrangement. This mass may certainly be regarded as a detached portion of the Marydale beds.

In the granite and gneiss lying between the hills flanking the Kaaien Bult and the Doornberg range, there are many streaks of metamorphic rocks in addition to the large areas described above. These smaller masses are particularly abundant between Spring Puts and the north end of the Vaalberg-Groot Modder Fontein belt. The rocks of these isolated patches are as varied as those of the larger belts, but pyroxene-granulites seem to be specially abundant in them.

On Spring Puts there are elongated but thin masses of dark greenish rocks lying parallel to the foliation of the gneiss. They vary in length up to 300 yards, and in thickness up to about 20 yards, though gneiss often occupies part of the width. One of these consists of hornblende, felspar, quartz, ilmenite, very little epidote and some apatite (2025). The hornblende is a strongly pleochroic green variety, and occurs chiefly in large ragged plates which occasionally show the prism faces; these large hornblendes enclose both quartz and felspar poecilitically; the same minerals form thin needles and thicker prismatic sections of small size in every part of the felspar in the slice. The felspar is partly plagioclase, but there may be some orthoclase; some of it (cloudy) seems to be the remains of the original felspar of a coarse-grained diabase, but other parts have a granular form, and are associated with quartz in the same form. All the quartz is granular, and does not look like an original constituent. In one place a group of epidote granules surrounds a grain of orthite.

Another group of outcrops in the same neighbourhood are (2026) actinolite-chlorite-schists with felspar and quartz-mosaic lying between the short crystals of actinolite; the chlorite is almost colourless in thin section, and forms well-defined flakes of a size large enough to give a micaceous appearance to the rock in hand specimens. These rocks show a varying degree of schistosity even in one and the same outcrop; some parts are quite massive, while others are very schistose. Four slices cut from different parts of one of these outcrops in the southern part of Geelbeck's Dam show degrees of change from a rock with much original plagioclase and pseudomorphs of uralitic hornblende after ophitically developed augite (2028) to a hornblende--felspar-quartz-epidote rock (2030) with pronounced schistose structure, though without the granulitic structure found in the more advanced stages of change in the Marydale beds. The felspar first becomes crowded with epidote grains of small size, and, in the case of porphyritic crystals, with sericite; the hornblende encroaches on the felspars of the groundmass; in the schistose condition the felspars are again clear, and the epidote grains have been consolidated; the process involves the obliteration of the original boundaries

of the felspars. The chief difference between this process of alteration and that observed in the Ventersdorp lavas, which lie less than a mile to the east is that the former results in the development of much felspar and well-defined hornblende, while the latter produces much fibrous hornblende, actinolite and tremolite, quartz and epidote, but the felspar is not regenerated.

On the farms Spioen Kop, Wyngaard's Pan, and Klein Witfontein, there are many small belts of basic granulites

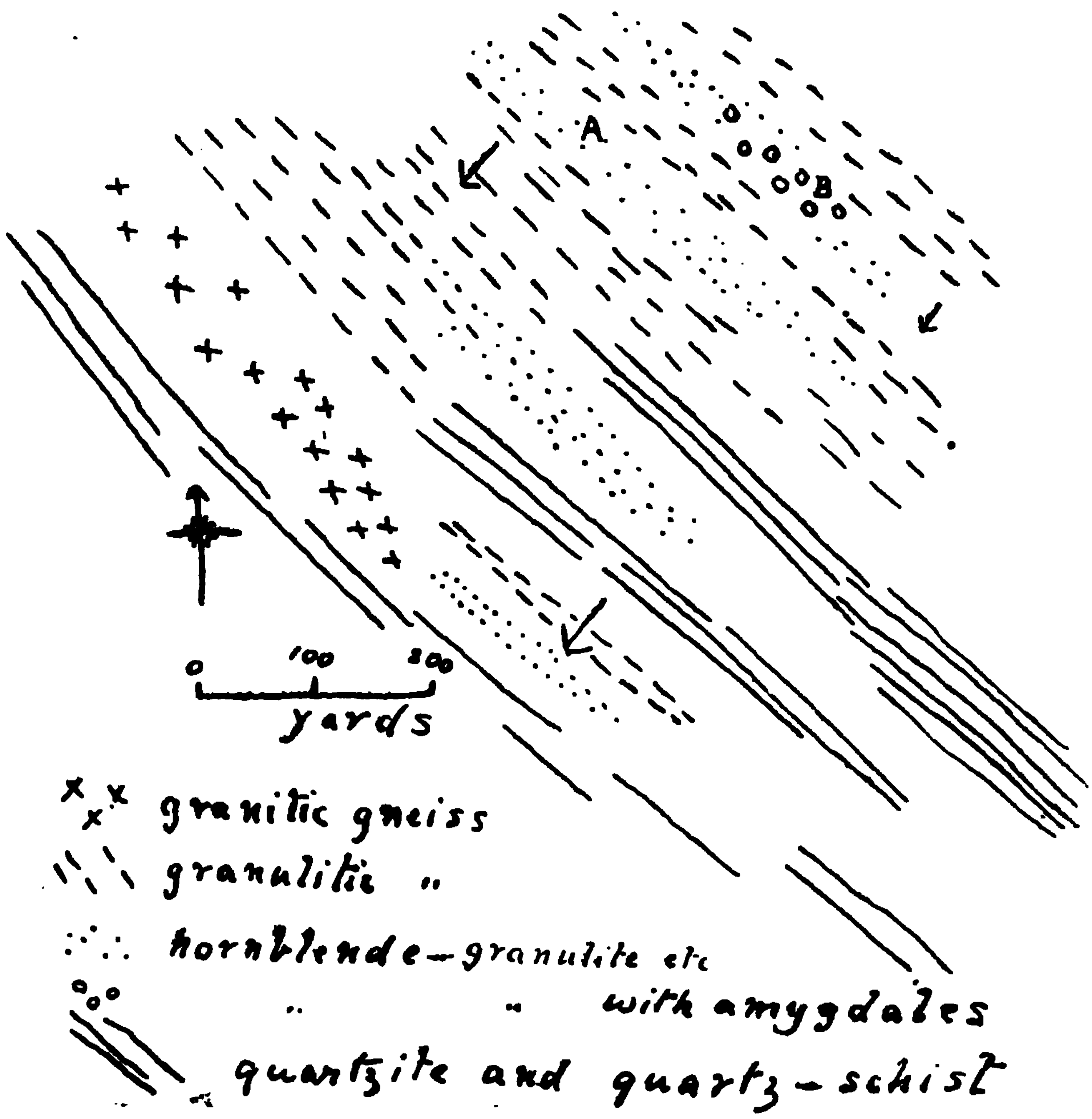



FIG. 8.—Outcrop on Wyngaard's Pan.

associated with banded grey acid granulites, both of which are penetrated by the granite, which also surrounds them. In some cases quartz-schists and quartzites are found in the same belt with the granulites. Though the occurrence of the thicker masses (up to about 400 yards at the most) of granulites has usually caused the formation of a low rise, where the outcrops are more plentiful than on the surrounding ground, the rocks in general are not well exposed.

The outcrops represented in Fig. 8, a plan of a low bult on

Wyngaard's Pan, show in a compact area the relationship of the chief varieties of rock in these belts. The dark granulites must have a considerable range of composition. A thin slice from A, in Fig. 8 (2159) shows much strongly pleochroic green hornblende in anhedral grains of various sizes, the larger having a poecilitic structure, enclosing quartz, felspar, garnet and magnetite; there is much quartz and less felspar, which is one of the less basic plagioclases, garnet and magnetite, often a small grain of magnetite is surrounded by garnet. The garnet is pink in thin section, and of all the constituents alone has occasional crystal faces; it encloses grains of all the other constituents, though this structure is not so well developed as in the hornblende. A few small grains or crystals of zircon are present. A section through an amygdaloidal granulite from this locality (B) (2158) shows less quartz and much more hornblende and felspar than the last, and, in addition, much bluish augite, which is very slightly pleochroic, some enstatite and sphene, but no garnet. The amygdales are elliptical patches of quartz in large irregularly shaped pieces, together with a very little felspar in some cases. The amygdales are abundant, and give both the weathered and fresh surfaces of the rock a characteristic appearance.

The grey granulite or granulitic gneiss from this locality has not been cut for the microscope, but a very similar rock from an outcrop further west (2157) is made of quartz, felspar (microcline and plagioclase), magnetite, biotite, some muscovite, sphene, and garnet in very small quantity. The structure is typically granulitic. These rocks are always banded, owing to the greater abundance of the darker constituents in some layers, and at places the bands are contorted. In the field the distinction between these rocks and those called granitic gneisses is obvious, though there can be little difference in composition in many cases; but the granulites are exceedingly difficult to distinguish from the quartzites in places, and there is evidently a continuous series with quartzites at one end and granulite with the composition of granite at the other.

In other specimens from Wyngaards Pan (654-656) the grey granulite contains many fair-sized pink garnets, which enclose quartz and felspar, but not biotite.

Occasionally, as between Spioen Kop and Wyngaard's Pan, there are rocks intermediate between the granulitic gneiss and the dark granulites. Some of them are amygdaloidal. Two thin slices (2167, 2168) from these rocks are made of quartz and felspar (in many cases andesine) with a fair amount of pleochroic epidote, less blue augite, some pink garnet, iron ores and sphene. There is no biotite or microcline in these specimens; another grey granulite from this area (2203) is made of quartz, oligoclase-andesine felspars, biotite in small quantity, garnet and magnetite. One of these granulites from

the south-east corner of Witfontein (2208) contains both microcline and albite, together with muscovite and a little greenish biotite, and the structure varies in the direction of micro-granite.

On the north-west part of Spioen Kop there are granulites (652-3) made of hornblende, biotite, plagioclase, quartz, sphene and magnetite, in which the hornblende is in large poecilitic plates and the mica flakes reach a length of ¼ inch. The granulitic structure is still very striking, though the rocks remind one strongly of quartz-mica-diorite.

Several sections have been cut from the dark granulites of Klein Wtifontein and Spioen Kop (2160-2166, and 2204-2206). Some of these are from amygdaloidal bands, but there is no general difference between the mineral composition of the amygdaloidal and non-amygdaloidal rocks. The constituents are felspar (andesine to labradorite), hornblende, blue augite, quartz, epidote, sphene, magnetite, and garnet. In some of them little or no augite is found, in others the augite is as abundant as the green hornblende. Generally all the constituents (except the quartzes and epidotes of the amygdales) are of more or less equal size, but in some cases there are rather large patches of augite and hornblende, with marked poecilitic structure; when there is much epidote the felspar is less abundant than usual. Quartz is not a very abundant constituent, though the amygdales always contain some quartz and often consist wholly of it. The amount of garnet varies, absent in some slices it is abundant in one (2162), but it is on the whole less abundant than in the hornblende schists in the Kaaien beds, which are without amygdales. A hornblende-quartz-felspar rock (639), from the west side of Spioen Kop, contains much idiomorphic garnet.

On Blaauwbosch Poortje there are at least three bands of dark granulites lying in gneiss between the quartzite of the N.E. beacon hill, and the main mass of Kaaien beds, west of the farm; some of the granulite is amygdaloidal. A thin section (2207) through one of these rocks shows more bluish augite than any of those hitherto mentioned, and little hornblende, together with much felspar (andesine-labradorite) and quartz, sphene and a little calcite complete the list of minerals seen. The augite forms large poecilitic plates enclosing grains of all the other constituents.

South of Groot Modder Fontein there are several small inliers, in the Dwyka, of quartz-schist and hornblende granulite, which are of considerable interest.

In the patch about one and a half miles due west of the homestead on Roode Vloer, a band of hornblende granulite, probably of small thickness, has been folded along with the quartz-schists, as shown in Fig. 9. The granulite is garnetiferous in places, but is not amygdaloidal. The most

interesting feature, however, is that the rock passes gradually into hornblende epidote (and zoisite)—granulite and then by diminution of the amount of hornblende and epidote into acid granulite and quartz-schist. There is a perfect conformity between the basic and acid rocks, except at one point, where a tongue of quartz-schist is surrounded by the hornblende granulite in such a way as to suggest that the latter is intrusive. In the hill, a little way to the east, there is again a zone of hornblende-granulite which, though extremely folded, and covering a wide area, is probably thin; it is quite conformable to the acid granulites, but at one point there are again some narrow veins of hornblende-granulite running into the lighter rock. The junctions between the two formations is nearly always very sharp, and there is hardly any of that transitional hornblende-

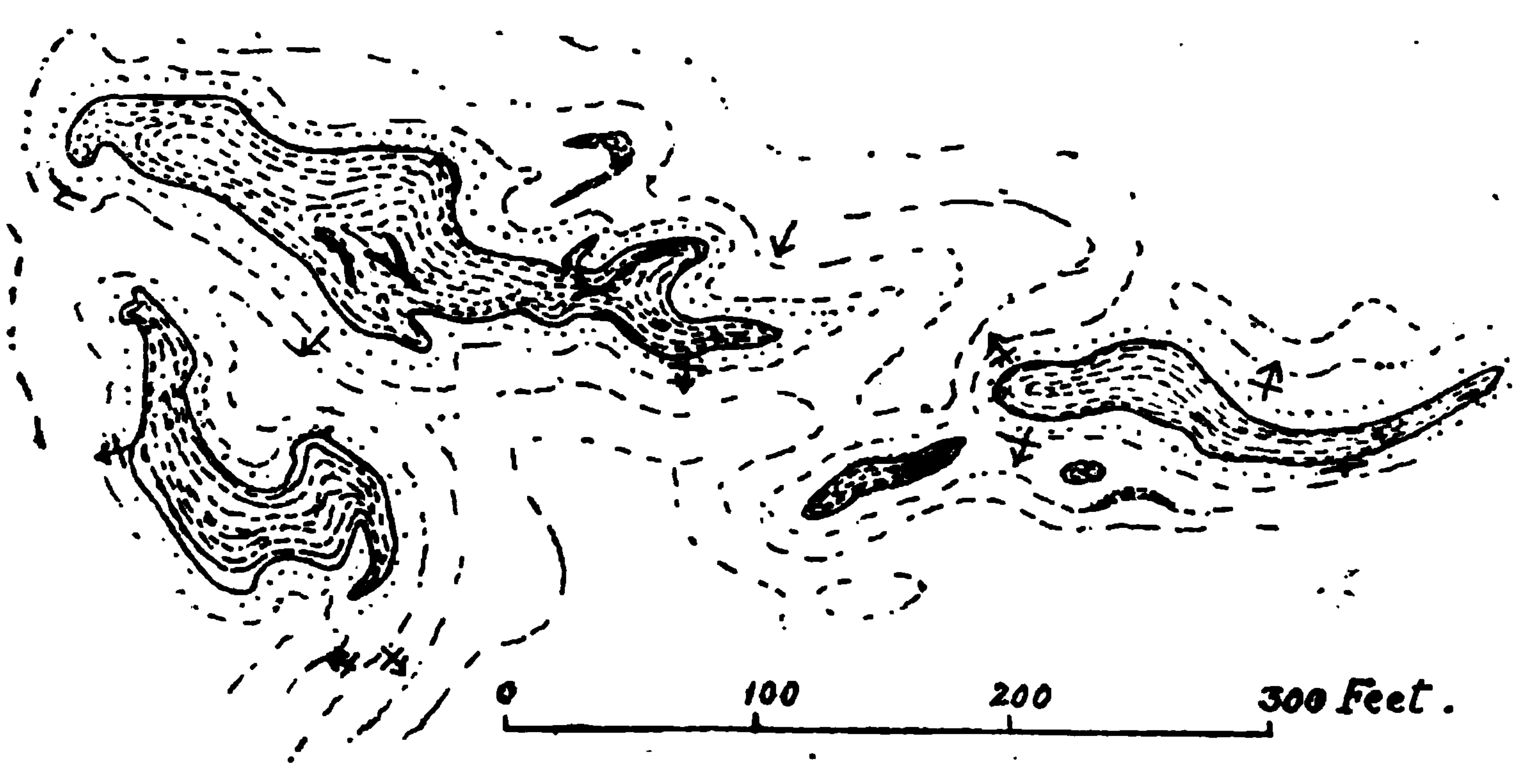



FIG. 9.—Plan showing areas of granulite surrounded by quartz-schist, Roode Vloer. Thick black lines indicate veins of granite and pegmatite.

-epidote-granulite seen on the western inlier. Further north on the south-eastern boundary of Klein Modder Fontein, there is another patch showing features rather similar to those of the first described inlier on Roode Vloer. Some of the quartz-schists show peculiar feathery growths of hornblende on the bedding planes, and by increase in the hornblende (and epidote) the rock passes into a hornblende-granulite. Whether the hornblende and epidote have been developed in this contact zone, three or four feet wide, at the junction of the two rocks by the metamorphic action of the granite, or the intrusive hornblende-granulite, is not quite clear. It is not unusual to find chlorite in this zone; for example, a thin section (2009) shows predominating chlorite in radiating masses with fairly large well-formed crystals of epidote. The spaces between the chlorite are filled with quartz in large areas, and a little untwinned felspar; in this the epidote is granular in habit. Iron ores are present as pseudomorphs after mica penetrating

the other minerals. These complexes are cut by veins of granite and pegmatite, and the latter type of intrusion is very common in the hornblende-granulites. In the eastern hillock, on Roode Vloer, there is a prospecting trench showing a vein in which quartz and white microcline felspar form crystals having a length of six feet. The two minerals sometimes form graphic granite, and contain large plates of muscovite mica, with an occasional crystal of garnet. Where the granite veins cut through the zone between the acid and basic granulites, there is usually a development of chlorite and garnet in the intrusion; garnet is commonly developed in both acid and basic granulites near the contact with granite and pegmatite veins.

The acid granulites, so well exposed in this hillock on Roode Vloer, are yellowish rocks which are friable when weathered. They are obviously quartz and mica-schists that have been impregnated with felspar derived from the numerous veins of granite which penetrate them, usually along the strike; in most cases the bedding or foliation planes are still recognisable. A short distance away from the granite the felspars are orthoclase and plagioclase; there may be a little epidote, biotite, muscovite, garnet, magnetite and sphene. Close to the granite, however, the felspar is usually microcline. In every case the structure is granulitic.

## *The Kaaien Beds.*

These beds occur in a broad belt traversed by the Orange River below the Ezel Rand. They form Buchu Berg, a range cut through by the river on the farms Luis Draai, Dabep, Buchu Berg, and Stof Kraal, where the strike is south-west, but on Keuk en Draai the strike turns south-south-west, and on the south end of that farm they are twisted, east-west strikes being seen. On the next farm, Karee Leegte, the strike turns slightly to the east of south, and further south becomes S.S.E. maintaining this direction, or veering towards S. 35° E., till the formation disappears under the Dwyka 100 miles from the Orange River, near Kheis.

Looking over the country from the high hills on the Kenhardt boundary (Keuk en Draai-Uitdraai) it is obvious that the N.N.W. strike is maintained for a considerable distance down the left bank of the Orange River, but that the north-east and N.N.E. trend carries the beds across to Kheis and the Scheurberg.

The higher hills are flat-topped, even though the beds are usually almost vertical. They rise to a height of 3,800 feet near the Orange River and 4,200 feet on Keuk en Draai, and the level of the summits is maintained southwards, though owing to the general surface of the ground rising in the same direction

the local differences in level are much less in the south than near the river.

The rocks vary from nearly pure quartzites to mica-schists.[1] In certain cases a very small amount of orthoclase, more rarely microcline felspar, is found, which in conjunction with the muscovite mica proves that the original sediments were felspathic to a small extent. In thin section under the microscope these rocks do not, as a rule, exhibit any remarkable features. In (2099) the junctions of the quartz areas exhibit a peculiar sutural character; the same is the case in (1984), only the areas are larger. In (1983) from the north side of Jackal's Water the muscovite forms large plates ophitically including quartz, and as the quartz is similarly oriented over small areas, the structure can really be termed micrographic. There is a large amount of magnetite distributed irregularly through the rock.

Magnetite is usually present in small quantities in the quartzites and schists, occasionally in very large amounts, either in irregular lenticles or bands, such as one on the top of the hill north of the Keuk en Draai-Uitdraai-Karee Leegte beacon (specific gravity 4), or as a well-banded rock, as, for instance, near the north-eastern beacon of Grenaat Kop. Epidote is occasionally sufficiently abundant to give the rock a green colour, as in a rock from the south-east flank of Buchu Berg on Luis Draai (2111), which is made of quartz with small epidote grains scattered through and between the quartz areas, and a very little chlorite.

No conglomerates of detrital origin were met with in this series; on Keuk en Draai there is a large mass of quartz-schist with several planes along which sericite has developed, so that the rock has a coarse, fibrous appearance; this rock encloses elongated spindle-shaped lumps of quartzite of various sizes, which look just like the stretched pebbles in the Matsap beds of Zeekoe Baart, but there is no doubt that they are pseudo-pebbles due to the breaking up of quartzite and quartz-schist. In one exposure there is a passage from the highly sheared rock with pseudo-pebbles to a massive quartz-schist within 30 feet. These pseudo-conglomerates occur where the Kheis beds are twisted in the southern corner of Keuk en Draai.

In the hills made of these beds the quartzites and quartz-schists are almost the only rocks seen; the mica schists have caused the formation of valleys, and are only seen on the low ground or in wells.

From Bosjesman's Berg southwards the Kaaien beds appear to form a syncline with quartzites and quartz-schists cropping out to the east and west, while a broad belt of mica-schist extends down the centre through Drielings Pan and Jonker Water.

It is extremely rarely that veins of granite or gneiss are found

---

[1] The descriptions on pp. 15-20 of Ann. Rept. G.C. for 1907 will apply to the rocks seen this year, and also those in Ann. Rept. for 1899, pp. 73-6.

on the higher ridges, but a notable exception occurs at the south-western beacon of Uitspanberg on the hill known as Vaalberg, where towards the summit there are quite a number of outcrops of coarse granite showing through the quartzite. Generally, too, the veins run along the strike of the sediments or cross them very obliquely. A good example of a granite dyke cutting through the strata at right angles to their strike can be seen just behind the spring below the homestead at the pan on Klein Modder Fontein. Again at the north-eastern beacon of Grenaat Kop a mass of Kaaien beds is traversed obliquely by long tongues of granite, gneiss, and pegmatite. Generally, large bodies of granite and gneiss occupy depressions more or less surrounded by quartzite hills, as on Brakbosch Poort, Rooidam, Eierdop, Kareeboom Put, and Grasbult. The junctions between the granite and Kaaien beds are difficult to lay down on a map, for, as on the north-east side of Upington Commonage, there is a gradual passage from rocks that are seen to be quartzites to the granite or gneiss. The typical gneiss is easily recognised, but wherever there are numerous outcrops along the junction rocks are found which look like quartzites in the field, but which contain much felspar.

On Brakbosch Poort two wells were seen on or near the contact zone on the north-east side of the hills. One of them is near the north-eastern house, and from it coarse augen-gneiss and fine-grained granulitic gneiss were obtained; this augen-gneiss is a biotite-gneiss with rounded orthoclase crystals in it, and it runs parallel with the banding in the fine-grained granulitic rock, and also breaks across those bands. Two thin sections from these rocks (2134, 2135) show that they are made of similar minerals, though biotite is much more abundant in the augen-gneiss; quartz, felspar (chiefly orthoclase and plagioclase, with a little microcline), biotite, sphene and magnetite are the only constituents seen. The structure of the fine-grained rock is not typically granulitic, though the minerals are in fairly equal sized grains; the dark layers contain more biotite that the pale grey bands. This rock seems to have much more quartz in it than the foliated gneiss. No quartzite was found in the spoil-heap of the well, though it crops out less than 100 yards to the west.

The second well, on the southern corner of the farm, has been sunk on the contact, and numerous blocks, partly made of glassy quartzite and partly of granite with pink felspar, have been thrown out. In many cases the glassy quartzite also contains some pink felspar, either in small patches or, as is more usual, in thin layers parallel to the junction of the two rocks. Occasionally a vein of granite seen in connection with the main mass of that rock runs into the quartzite. A thin section (2131) through one of the finely banded specimens shows much quartz, and a little felspar, muscovite, and magnetite; the felspar is orthoclase and plagioclase, with a very little microcline,

Another section (2133) from a quartzitic rock contains both orthoclase and plagioclase, though in small quantity, and also muscovite, magnetite and epidote surrounding kernels of orthite. A slice (2132) through a portion rich in felspar contains some orthoclase and very much plagioclase, apparently both albite and oligoclase on the evidence of their refraction compared with that of quartz, some muscovite and magnetite. The rock is almost certainly a granite, but there is a series connecting such rocks with quartzites in which no felspar is seen.

On the south-western flank of the hills near Brakbosch Poort there are often seen rocks of a grey colour and with the appearance of felspathic quartzites, occasionally banded with lighter and darker layers. In thin section (2127-2129) they are seen to be granulites with much quartz and acid plagioclase and a varying amount of biotite, muscovite, epidote (with orthite kernels), magnetite and apatite. The muscovite often forms large plates enclosing quartz or felspar. They are very different in appearance from the gneiss beyond the belt, but their separation from the quartzites is very difficult, and in the map they were put in with the Kaaien beds. They are very like the grey granulites in the Marydale beds. Layers of gneiss and coarse pegmatite are frequent in this grey granulite belt, and hornblende-schists are also present.

Similar grey granulites are found further south still along the western portion of the belt on Nels Poortje, Volgelstruis Bult, Drieling's Pan and Plat Sjambok, and are often very difficult to differentiate in the field from the intrusive gneiss; along with them are streaks of hornblende-schist and augite-granulites.

The development of felspar in the quartzite and mica-schist at the contact with granite and pegmatite can be well studied at numerous points along the southern extremity of the Kheis belt. For example, a couple of miles north-west of the homestead on Jonker Water a section (2269) of the quartzite cut through by a dyke of granite shows the following features. The quartz shows sutural boundaries, and between these areas are small patches of clouded orthoclase; there is some muscovite, and a little biotite mica, rather irregularly bounded, and looking as if they had been attacked by the granite magma; they occur along with epidote, magnetite, apatite, and zircon. There is some water-clear microcline and albite in irregular areas, and the rock would be termed a granite were is not for the abundance of quartz present. At the north-eastern corner of Grenaat Kop there are banded streaky mixtures of gneiss, acid granulites, and quartz-schist, and some of the granite veins are extremely rich in haematite, a few of the intrusions, in fact, consist of quartz, muscovite and haematite, the latter in crystals often over half an inch across. This recalls a vein of similar material from six to twelve inches wide cutting the Marydale hornblende-granulites on Groot Modder Fontein; this rock consists of quartz, felspar, and muscovite, while the crystals of haematite are occasionally over an inch across.

On the west side of the ridge, on Grenaat Kop, there is a hillock about 60 feet high and 300 feet long, formed entirely of a dark greyish fine grained rock which, in thin section (2270), proves to be a cordierite-sillimanite schist. The junction with the quartz-schists is nowhere exposed, but at one point there is an interbedded layer of quartzite about two inches thick; the rock has been invaded by granite and pegmatite, while there are numerous narrow veins of quartz. The section shows long ragged prisms of sillimanite indefinitely terminated and aggregated together to form bands, producing a foliated structure in the rock. The groundmass is water-clear cordierite, which would be taken for quartz were it not for the characteristic pleochroic halos round the inclusions of magnetite and zircon. On the south-east side the schist comes almost into contact with a hornblendic rock (composed of quartz, plagioclase and hornblende), which shows no features of interest.

A band of hornblende-schist in the grey granulites outside Brakbosch Poort (2126) is made of quartz and plagioclase, probably also orthoclase, green-blue hornblende, garnet and magnetite. The hornblende and garnet are in rather larger individuals and enclose rounded bits of the other minerals; the felspar is considerably altered.

There are many long thin streaks of various kinds of hornblende schist in the gneiss area outside the Brakbosch Poort hills from the neighbourhood of Puts Zonder Water down to Saft Sit; some of them are of the same character as the hornblende-schist in the grey granulite just mentioned, others (595, 597-8-9) are made almost entirely of large actinolites with very little quartz. Others, again, have large amounts of epidote in them together with dark green hornblende, but in these felspar is absent (596). In the hornblende-schists, often garnetiferous (590-594, 600-603), there is a considerable range in the composition of the hornblende, as shown by its colour and pleochroism, from actinolite to a deeply coloured hornblende; the felspars are plagioclase, and there is much quartz; the structure varies from granulitic to schistose, and some of the rocks might be called hornblende-gneiss. Granite veins penetrate these schists, and there is a great contrast between the two rocks owing to the absence of micas from the schists. One type of rock seen in the granite W.S.W. of the Poort presents unusual characters; "eyes" of felspar crowded with secondary minerals, of which epidote is the most conspicuous and the only one determined, are surrounded by a schistose mass of dark green hornblende, quartz and epidote. There are a few occurrences of fine-grained quartz-epidote rocks (605, 606), with marked banding; the microscopic structure of these resembles that of cherts.

So far as is known amygdaloidal structures do not occur in

the hornblendic schists or the basic granulites, which will be described below, on the south-western flank of the Kaaien hills. That in many cases these various rocks are older than the granite is proved by the intrusions of the latter, but what their original nature was is not known. In many cases they resemble parts of the schists and granulites included in the Marydales, but beyond this general similarity and the probability that they are metamorphic rocks of an extreme type there is no clue as yet to their origin.

The country south-west of the hills is not favourable for geological mapping; there are few hills, and the gently undulating surface of the Bult is to a great extent covered with red sand and surface limestone; outliers of the Dwyka series also conceal the older rocks, and their limits are exceedingly difficult to define. The rocks dealt with in this section form low outcrops amongst gneiss and granite on the farms Brakbosch Poort, Geluk Pan, Eiderdop, Kraanvogel Pan, Saft Sit, and Doonies Pan. In many cases the rocks form belts traceable for some hundreds of yards in a north-north-westerly direction parallel to the strike of the Kaaien beds and that of the gneiss.

On Geluk Pan the granulites (608-611, 613-619) are made of labradorite, colourless and blue augite, pink garnet, epidote and sphene, with occasionally a very small amount of a deep green mineral with the optical properties of aegerine grown on to the blue augite. None of the minerals have crystal forms; the felspar often occurs in large masses enclosing grains of the other constituents; the augite also forms large plates enclosing felspar as well as the other constituents. In several cases there is a sort of intergrowth of felspar and augite, each extinguishing uniformly over a considerable area. The epidote (pistacite and clinozoisite) often forms thin films round garnet, less frequently round augite grains. As in almost all the Prieska granulites, the minerals are fresh. There is neither quartz in these rocks, nor magnetite.

On Kraanvogel Pan there are two kinds of granulites, one (620, 624) is made of quartz, plagioclase and a small quantity of green hornblende, magnetite and sphene, without epidote or garnet; the other is characterised by the presence of much blue augite, yellow epidote, garnet, a basic plagioclase and very little quartz, and very little or no magnetite and sphene (625-630). The plagioclase tends to form large plates enclosing the other minerals; hornblende is not seen in these rocks.

On Saft Sit at least three varieties of dark granulite were found. In the palest kind (631-2-3) the rock is chiefly made of plagioclase (oligoclase-andesine), quartz, and varying amounts of rather deeply coloured greenish-blue pleochroic augite, with a little magnetite and sphene. Another kind

(2151) is made of labradorite, blue-green augite often crowded with minute dusty inclusions, garnet, epidote, and very little magnetite and sphene. The felspar forms large plates enclosing all the other constituents; the garnet is in small and curiously shaped grains; the epidote occurs in small grains, and also in thin films surrounding augite and garnet grains lying in the felspar. The third kind (2150) is a coarse grained granulite made of labradorite, dark green hornblende, blue augite, with very little epidote.

A well and bore-hole at Doonies Pan have been sunk in granulitic rocks. Two sections (2153 and 2154) from about 150 feet and 200 feet respectively, in the bore-hole, show interesting features. The first section is made of labradorite, rather bright green hornblende, very pale green augite, and slightly pleochroic hypersthene; there is no epidote, garnet, iron ore or sphene. The hypersthene is slightly altered along the edges and cracks. The rock from below 200 feet is intermediate in structure between the granulites and gneiss; it is made of oligoclase, quartz, green hornblende, red biotite, ores and apatite. Below this rock a biotite gneiss was met with. The rock from the surface down to about 40 feet in the well is a dark hornblende-hypersthene-labradorite granulite with a little quartz, magnetite and red biotite (2155). This rock is traversed by veins of grey gneissose granite with large felspars. The well and hole are close together, and the uppermost 100 feet or so of the bore-hole were said to have given a core very like the rock from which (2155) was cut.

In the south-west part of Doonies Pan there are outcrops of a dark brown rock showing marked "lustre-mottling" on fresh surfaces; they are traversed by numerous veins of granite. The rock (2156) is made of large interlocking plates of labradorite enclosing small but very abundant grains of blue-green augite, garnet and epidote. The shape of the garnet grains is peculiar; they are often curved, and in some cases partly surrounded by epidote. There are no ores or sphene.

On Kareeboom Puts there is a streak of granite about 2½ miles long, and only a few hundred yards wide, along the strike of the Kaaien beds; on the south-west flank of this granite, separating it from the quartzite outcrops, there is a dark granulite with peculiarly complicated microscopic structure. The constituents are dark green hornblende, colourless garnet, very pale augite, plagioclase, quartz, magnetite and rutile written in the order of their relative abundance. There is a parallel structure, due partly to the fact that the larger hornblendes lie with their longest axes in one direction, and partly to the presence of strings of felspar and quartz grains parallel to that direction. The hornblende and garnet enclose pieces of the other constituents. The augite forms curious inter-

growths with quartz, and these quartz-augite patches cover rather large areas and enclose pieces of hornblende, magnetite, quartz, rutile and garnet. Whether the colourless mineral is in all cases quartz is doubtful, but in one or two cases it certainly is, and twinning was not seen in any of them.

Further south, about a mile from the homestead on Vogelstruis Bult a narrow zone of granulite is found in contact with granite. The section (2279) shows blue-green augite, irregularly shaped and full of inclusions of felspar, labradorite in small polygonal areas, and a little quartz epidote and sphene.

On the road between Plat Sjambok and Jonker Water there is a narrow band of granulite in quartz and mica schist, and with no granite in the vicinity. The section (2268) shows labradorite, quartz, greenish augite and irregular garnets, each surrounded by a shell of epidote.

## The Granite and Gneiss.

As stated on previous pages, the granite and gneiss form elongated areas or streaks alternating with and including portions of the Kheis formation into which they are intrusive. Generally the granite gives rise to low sand-covered country, and good outcrops are not very numerous. Just outside Prieska Poort there is a very good example of a granite knob or " tor "; a second example is Water Kop, a little further to the west.

The rocks vary greatly in character and composition from point to point; over the greater part of the area a gneissose structure is well developed, and gneissic varieties alternate with belts of compact unfoliated granite. The foliation planes generally strike N.W. or N.N.W., parallel to the Kheis ridges, but there are numerous localities where they possess a more easterly direction, and this is especially the case between Wit Vley and Marydale; on Nooitgedacht they strike nearly north and south. Throughout the area, however, the streaks of Kheis rocks in the granite follow fairly closely in their direction that of the foliation planes, and it seems very likely that these foliated and banded structures have been given to the rock during its invasion of the Kheis formation. The banded character may in part have been produced by differentiation and flow of the material previous to its consolidation, in part to the absorption of inclusions of the invaded sediments and volcanics.

In a number of places the granite and gneiss have been considerably sheared, and the rocks converted into a peculiar hard flaggy material which has a great resemblance to a quartzite in the field. There are several of these belts of shear close in under the Doornberg striking in a direction parallel to the big ridge, and the innermost of these belts runs

along the fault by which the granite has been brought up against the Black Reef series. These belts usually produce low ridges.

A section of a normal granite (458), three miles west of Prieska Poort, shows large areas of orthoclase containing inclusions of epidote and muscovite surrounded and penetrated by clear microcline, the two felspars possessing a similar principal cleavage. The microcline is intergrown with quartz and biotite, the latter associated with epidote, zoisite, and sphene. Sections (452, 457) of a coarse-grained fissile gneiss from the same locality show sub-angular fragments of orthoclase, plagioclase and microcline set in a groundmass of crushed quartz and felspar with flakes of biotite and granules of epidote and sphene. In the westernmost line of kopjes outside Prieska Poort there is a belt of flaser-gneiss showing (1980) felspars crushed and traversed by lines of shear, along which the mineral has sometimes been granulitised. The matrix is a fine-grained aggregate of quartz and felspar, across which the lines of shear are marked by streaks of greenish mica and granules of epidote. Along the Doornberg fault at Prieska Poort the gneiss has been converted into a mylonite, and a section (1978) shows small "eyes" of microcline felspar chiefly, and occasionally of quartz, set in extremely fine "laminated" groundmass containing small areas of carbonate and small needles of an amphibole allied to glaucophane. Sphene has developed from the iron ores. In another variety (1977) the crushing has not been so intense, but small rods of glaucophane are arranged in bands and streaks curving round the large quartz and felspar relics. There are small granules of epidote and streaks of sphene. In a darker blue-grey rock (1976) there has been further recrystallisation of the felspar, and glaucophane and epidote are more abundant and form larger individuals. Section 454 is taken from a greenish grey rock with dark streaks, and contains large epidotes, sometimes almost idiomorphic and frequently possessing good cleavages. The groundmass is principally a water-clear felspar, probably albite, with some quartz, epidote, and a good deal of glaucophane. Magnetite is abundant, and forms long strings of small areas sometimes with geometrical outlines. It seems probable that the glaucophane and epidote have been developed in such portions of the granite as have been intensely sheared, for a section (455) of pink gneiss shows the formation of needles of glaucophane in the felspar areas. Along all these belts the dip of the planes of shearing is at a high angle to the south-west.

At the homestead on Vogelstruis Built a well has been sunk on a fault line in the gneiss, and some of the material thrown out consists of blocks of banded gneiss set in a finely mylonised dark material; it is evidently a "crush-conglomerate."

The normal gneiss, however, possesses a structure quite different to that of these crushed and sheared granites, the granulitic and cataclastic structures in the latter being clearly due to earth movements long subsequent to the consolidation of the igneous rocks.

The granites vary considerably in character from point to point. The most common type is a gneissic muscovite granite containing microcline orthoclase and plagioclase felspars, biotite varieties are not so frequent. A peculiar character, which appears to be not uncommon, is the surrounding of the orthoclase felspar by the microcline, as in the example (458) quoted previously.

In a slide (525), cut from a granite from a prospecting shaft on Schalk's Puts, the areas of microcline are larger and enclose numerous small slightly clouded individuals of orthoclase and plagioclase felspar; the biotite has been converted into chlorite.

A granite (2274) from a well on Boschjesman's Berg shows long prisms of clouded orthoclase surrounded by microcline. Hornblende is abundant along with biotite, sphene and apatite. Another hornblende variety occurs on Water Kop. As mentioned in dealing with the Kheis formation, there is in places a gradual passage from the granite into acid or basic granulites representing metamorphosed sediments and igneous rocks respectively, and it is evident that these metamorphic products might ultimately have diffused through the granite magina and have become absorbed by it. This is shown in many places by the presence in the granite of small garnets, sphene, iron ores, and occasionally staurolite, sillimanite and cyanite in small quantities. The three last-mentioned minerals are present, for example, in the gneiss which occurs a little to the north-east of Saft Sit Pan.

Veins of coarse granite and pegmatite are numerous in the Kheis beds, intruded most frequently along the bedding planes; usually they contain muscovite mica and sometimes garnet.

The Kheis rocks, more especially the Marydale beds, are frequently traversed by quartz veins which, in a large number of instances, are found to contain here and there small patches of muscovite mica and sometimes felspar. There can hardly be any doubt that many of these veins are really extremely siliceous offshoots from the granite formed during the final consolidation of the latter; in some places a granite or pegmatite dyke can be found, on being traced, to pass gradually into a vein of quartz.

Such veins are especially numerous in the eastern half of the belt of amphibolites and granulites stretching from Vaalberg to Groot Modder Fontein.

The granite and gneiss west of the Brakbosch Poort hills are of the same general character as those to the east of the

hills; they rarely form kopjes, but at Put Zonder Water there are three prominent kopjes made of huge boulders of a rather fine-grained grey granite. Sections of this rock (2124-2125) show that it has suffered from pressure to a greater extent than would be suspected from its appearance in the field. The constituents are microcline, orthoclase, albite, quartz, biotite, chlorite, epidote and allanite, apatite, magnetite, fluor and zircon. The structure is granitic with occasional patches of micropegmatite, but the larger quartz and felspars are much strained, and there are granulitised borders round them characteristic of such rocks after subjection to great pressures.

## THE VENTERSDORP SYSTEM.

Rocks belonging to this system are found almost continuously from Groot Wit Fontein to Ezel Rand, a distance of 40 miles, and at a few spots near Prieska's and Keikam's Poorts. They are not found in the position where their presence would be expected, between the Black Reef on the north-east and the granite on the south-west, for many miles south-east of Groot Wit Fontein, and they are absent from analogous positions for shorter distances on Geelbeck's Dam. The explanation of these facts is found in the thrust-faults along the south-west flank of the Doornbergen, which have been dealt with in the introductory part of this Report.

In former Annual Reports the Ventersdorp formation has been divided up into three subgroups, the Pniel, Kuip and Zoetlief series, but in the area surveyed last year it was found impossible to follow this classification thoroughly in the process of mapping, for the rocks have suffered so greatly from mechanical disturbance that the original stratigraphical relationship of the subdivisions, if present, has been obscured. Previous experience shows that though the three series are broadly characterised by different petrographical types of lavas, yet these types are not confined to particular series, so they cannot be relied upon exclusively in mapping the series without the aid of stratigraphical evidence.

At the south-east end of the strip of Ventersdorp beds flanking the Doornbergen, the first rocks that can be included in that group are rather peculiar sheared quartz-porphyries. They have a slaty structure, and the crystals of quartz and felspars form " eyes " in the sheared matrix. The quartz has a blue opaline appearance in hand specimens. Two thin sections (2169, 2170) have been cut from this rock on Groot Witfontein. The porphyritic quartz crystals are rounded and penetrated by corrosion cavities; the felspar crystals are not so rounded, the material is fairly fresh,and from the extinction angles and the fact that Becke's test shows that several of the repeatedly twinned crystals are less refractive than quartz,

the felspar is probably albite in several cases. The matrix is microcrystalline and consists of quartz, small flakes of brownish green mica often changed into chlorite, white mica, and magnetite. Probably felspar is also present in the groundmass, but it was not determined. These sheared quartz-porphyries extend rather over four miles in a north-westerly direction. On the north-east they are in contact with the vertical or highly inclined quartzites of the Black Reef series for two miles, but near the road from Groot Wit Fontein to Kalk Fontein blue amygdaloidal diabase, of the kind usually found in the Pniel series, comes in betwen the two rocks. On its south-west side the porphyry is flanked by granite except along a short distance at the extreme south-east end, where the nearest rock seen is a schistose quartzite which is probably a part of the Kheis group. The quartz-porphyry dies out near the boundary between Wit Vley and Klein Wit Fontein; its average width is about 200 yards.

On Geelbeck's Dam quartz-porphyries are again found between the Black Reef quartzites and the granite in one place, and between granite and blue amygdaloid further north-west.

The blue amygdaloidal lavas of the Pniel type are first met with on the road from Groot Wit Fontein to Kalk Fontein. Their base is not exposed, but the next rocks seen to the west are green schistose beds with which are associated sheared quartz-porphyries with blue quartz described on the last page, and which possibly belong to the Zoetlief series. The lavas are blue amygdaloidal rocks, and have not been much altered. South-east of this locality no Pniel beds are seen for miles. North-west of the road the band of Ventersdorp beds widens out to nearly 1,400 yards, but it becomes narrower and again increases in width south of the middle beacon on the east side of Wit Vley. The beacon stands on the hills made of Black Reef quartzite, and the junction with the lavas is well exposed on the south-west and north sides of the beacon hill. The normal condition of the succession is seen round an anticline of Ventersdorp beds surrounded by Black Reef quartzites on the southern part of Nauga. The area of Ventersdorp beds is $2\frac{1}{2}$ miles long, and consists of amygdaloidal lavas, breccias, and flagstones; these beds are overlain by quartzites and limestone forming the base of the Black Reef series. Directly north of the beacon, on the slope of the hill, there is a small inlier of volcanic beds, which include a band of coarse conglomerate with boulders of lava and quartzite up to two feet in length, lying between blue amygdaloidal lavas just below the base of the Black Reef. On the hill-side south-west of the beacon there is a clear section through the junction of the Black Reef and the Ventersdorp series. The Ventersdorp beds have been thrust over the basal part of the Black Reef, including the limestone band. The fault is well exposed, and there is some

breccia along it, made of fragments of the lava and of quartzite set in a limestone matrix. The lava is an amygdaloidal rock, pale reddish in colour, and more acid than the usual blue lavas, in fact it was taken to be part of the garnite when first seen, but the amygdaloidal bands in it showed its nature. Three thin sections cut from pieces of the lava (2174 from the lava near the fault, 2175 from an amygdaloidal band in the lava, and 2177 from a fragment in the fault brcecia) all show the same characters; the rock is made almost entirely of quartz and felspar; the felspar is rarely twinned, and is probably all orthoclase, for it is less refractive than quartz in every case tested; the structure is felsitic with a tendency to a radial arrangement, so that there are ill-defined rather large spherulites. There are no crystals with plane faces, but there are patches with ill-defined or disturbed micrographic structure. The larger quartz areas show marked strain effects, and the same effect is seen also in the small areas but less clearly. There is no mica or hornblende, and the small amount of iron ores originally present have been altered to rusty patches. The amygdales are of quartz.

The junctions with the blue amygdaloidal diabase, which crops out to the east, is not exposed, and the thick band of coarse conglomerate appears to lie above the blue lava. (See Fig. 10.) The conglomerate has a gritty matrix containing much quartz and felspar; the boulders are well rounded and of large size; they seem to be chiefly pale felsitic lavas just like the rock at the fault, but there are also quartzites and diabase lavas among them. The junction with the gneissose granite to the east is not exposed; it may be an unconformity, but from the general distribution of the rocks along this boundary it is much more likely to be a second thrust fault.

Following the band of Ventersdorp beds towards the N.N.W. along the flank of the Black Reef hills, it is found to disappear on the southern part of Geelbeck's Dam, where the Black Reef is in contact with granite for a few hundred yards. The beacons common to Geelbeck's Dam, Spring Puts, Nauga and Lot A of Wit Vley stands on a high ridge of the Black Reef series; both east and west of it there are amygdaloidal diabase lavas and green beds; those to the west are greatly sheared, the lavas being reduced to slaty rocks with "eyes" formed by the amygdales. To the west of the quartzites there is an anticline of these rocks in a much less sheared condition; this anticline of volcanic beds terminates on Nauga. A thin section from a rock in this band with amygdales of quartz (2031) is made chiefly of quartz and plagioclase felspars, with a considerable amount of tremolite in bunches of needles and a little magnetite and brown mica in small scales. Some of the felspar occurs in lath-shaped sections and is an acid oligoclase, but it is in part replaced by a fine mosaic of quartz, very like

the general groundmass of the rock. The slice passes through two amygdales which are made of quartz-mosaic with a large amount of tremolite needles and brown mica flakes.

This rock has evidently been much altered, but further north, between Geelbeck's Dam house and the mountains, rocks in the same anticline, here truncated obliquely by the granite along a fault, show more usual features. The volcanic rocks seen nearest the granite along the track to the mountains are grey amygdaloidal lavas with corroded quartz blebs, the remains of porphyritic crystals. Under the microscope this rock (519) is seen to consist of a groundmass of felspar laths and microlites in a devitrified base, containing amygdales of quartz, chlorite and calcite. There is no ferromagnesian constituent. The felspar is still fresh, and is an acid plagioclase, but there are scales of sericitic mica in it. The iron ores are altered to dull opaque matter. Other lavas from this neighbourhood are more basic in composition; they are blue or green rocks, often amygdaloidal. Three sections (518, 521, 522) from them show similar characters; they consist of

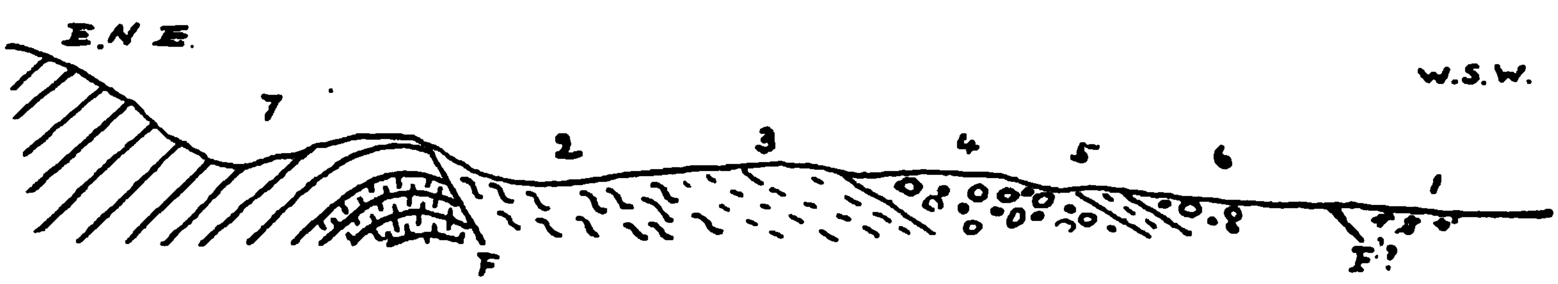



FIG. 10.—Section through the junction of Ventersdorp and Black Reef beds on Wit. Vley. 1, granite; 2, rather acid lava; 3 and 5, blue amygdaloid; 4 and 6, conglomerate; 7, Black Reef series, with limestone near the base. F, faults.

felspars, chlorite, calcite, quartz in a very fine-grained mosaic in the groundmass, and altered magnetite or ilmenite. The felspars are of a more basic kind than that in the rock just described and form stouter crystals. There is no original ferromagnesian mineral left, but the abundant chlorite, which is distributed throughout the rocks, represents such a constituent. The calcite is also uniformly distributed in the form of small grains, and may be an alteration product. A vein containing galena was opened up in an altered lava on Geelbeck's Dam; the slice (520) shows the rock to be made of small plagioclase crystals and alteration products, a fine-grained chalcedonic quartz-mosaic and flakes of sericite, with small dull patches representing iron ores.

As is often the case with the Ventersdorp lavas, it is difficult to observe the dip of the lavas in this area. The rough cleavage has a steep dip to the W.S.W., and in places the green flaggy beds occasionally seen interbedded with the lavas have a similar dip, as have also the quartzites of the Black Reef series, but as a rule the beds are steeply inclined towards E.N.E.

North-east of the house on Geelbeck's Dam the Black Reef

series again comes into contact with the granite, but only for a mile, and over part of that distance the rocks are concealed by a gravel fan opposite a kloof in the mountain. For some four miles on the northern part of Geelbeck's Dam and the eastern corner of Kameel Boom, the Ventersdorp beds lie between granite on the west and either the Campbell Rands beds or the Griqua Town series on the east. The rocks here are amygdaloidal and compact green diabases with intercalated green tuffs. They dip at high angles eastwards, and measure over 1,500 feet across the strike, but it is uncertain whether they are repeated by folding. Near the Orange River on Westerberg[1] the volcanic rocks are considerably sheared, and they include a lenticular mass of quartzite, which makes a prominent hill. This quartzite abuts against the Griqua Town beds on the south-east, and thins out on the south bank of the river at the other end. It is like the Black Reef quartzite further south and north, and is probably a synclinal fold of that rock, for a certain band of calcareous rock, brown in colour, intercalated between blue amygdaloidal lavas, occurs on both sides of the steeply inclined quartzite. A thin section (2038) through this rock shows it to be made of calcite or dolomite mixed with fine-grained detrital quartz and plagioclase felspars and some chalcedonic silica, magnetite, very small flakes of a pale green amphibole, sericite, and patches of brown opaque matter, probably hydrous oxide of iron, at places showing rectangular and rhombohedral outlines. It is probably a calcareous tuff. Another tuff from Westerberg (2042) is a roughly cleaved rock made of chlorite, silica and small amounts of opaque matter, rutile and calcite. No felspar is visible.

Hitherto epidote has not been mentioned as a constituent of the lavas along this belt, but one of the Westerberg lavas (2043) contains a fair amount of it. The rock consists of plagioclase (oligoclase) in rather small but not very narrow crystals set in a matrix of secondary silica, epidote, calcite and chlorite, with altered iron ores; there may be felspar in the matrix also. The epidote is yellow and pleochroic. Another rock from the same neighbourhood (2044) is similar to the one described except that there is no epidote but more felspar and calcite in the matrix. In the hand specimens both these rocks are without amygdales and show incipient cleavage.

From Kameel Boom the western limit of the Ventersdorp beds has first a north-westerly and then, on Greeff's Puts, a westerly course as far as Blaauw Puts, while the eastern edge keeps a northerly direction; the result of this is to allow the beds to occupy an area 10 miles wide on Blink Fontein and

[1] This property includes the eastern corner of the Kameel Boom section of Rietfontein.

Zeekoe Baart. The western boundary is not well exposed, being obscured by sand over almost the whole of its course.

At Klein Schalk's Puts the junction of the granite and the Ventersdorp lavas is exposed for a few yards in the bed of the river near the homestead, as shown in the plan Fig. 11. The lavas are very much cleaved, and there is a brecciated

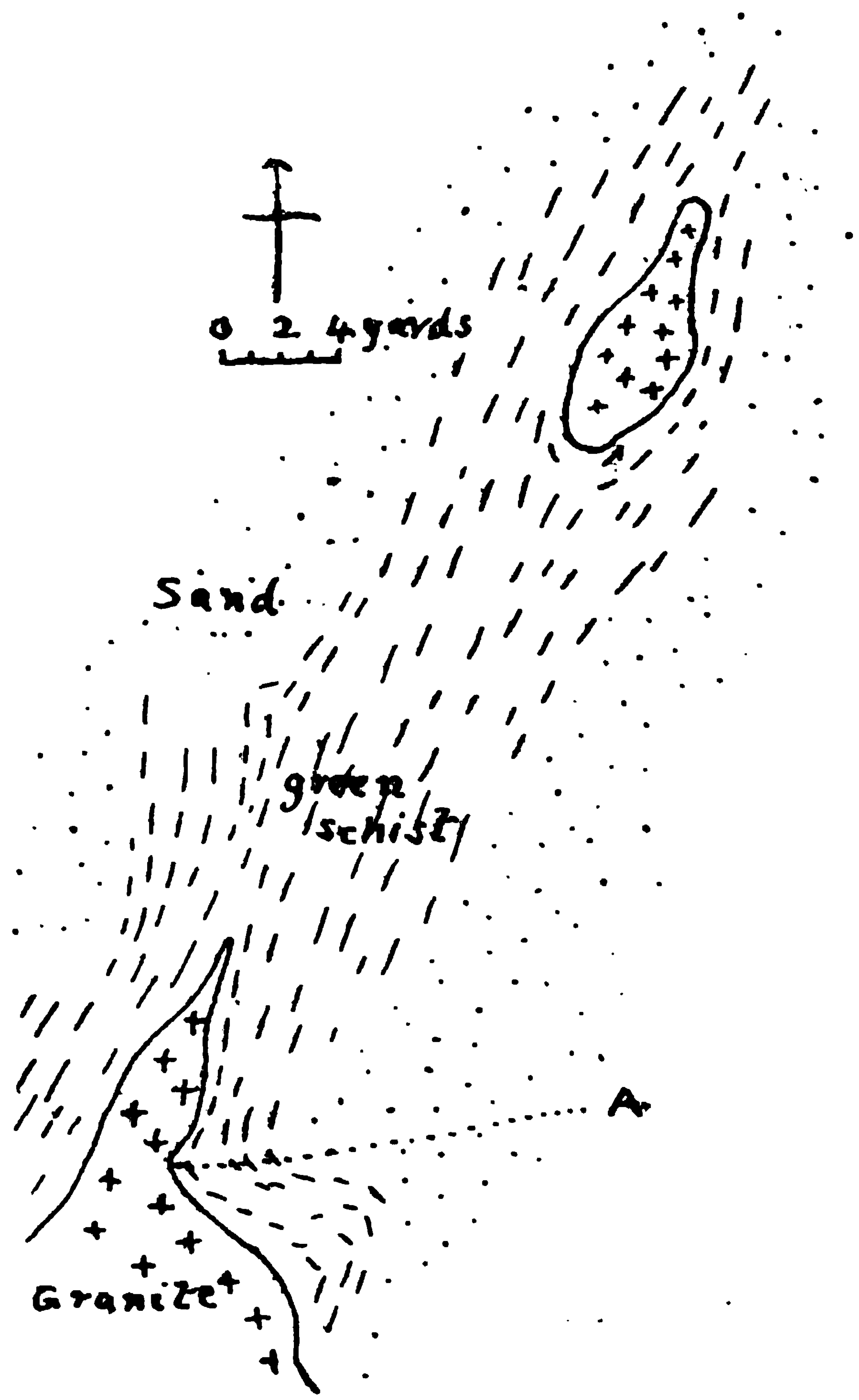



FIG. 11.—Junctions of granite and schistose lava on Klein Schalk's Puts.

structure at places along the contact. A large mass of granite lies completely surrounded by the sheared lavas, and the quartz amygdales in the latter have been pulled out, broken transversely and flattened. A thin section cut from the lava at the point A in Fig. 11 shows a fine-grained rock made up of very small plagioclase laths which extinguish nearly straight, and a large amount of pale greenish chloritic material with small

patches of granular sphene. In the chlorite there are also a few very minute flakes of a slightly pleochroic mica. The breccia along the contact is a green slaty rock containing fragments of granite, round which the shear-planes bend. The only places along the boundary where the contact was seen are at Klein Schalk's Puts and Schalk's Puts, elsewhere, so far as observations were made, the contact is concealed or the rocks so weathered that they are useless for close study. Both the above specimens from Klein Schalk's Puts, and those described below from the prospecting trenches, show clear signs of metamorphism by pressure and movement, but, excepting the few minute flakes of mica in the chlorite, none that could be due to the intrusion of granite amongst the lavas. The pale mica flakes seem to have developed in the chlorite, which is probably the product of weathering of the ferromagnesian constituents; it is much paler in colour than the coloured micas of rocks altered by igneous intrusions, and is much less abundant than those minerals in such rocks. The contrast between these specimens taken from within an inch or two of the granite and the lavas of the Marydale beds, described earlier in this Report, is very great; these rocks lack the pyroxenes, deeply coloured hornblendes, garnet and the recrystallised felspars of the latter.

At Schalk's Puts a shaft has been sunk on a quartz reef containing some copper ores and forming a slight ridge. The quartz reef traverses both the lavas and granite, but is not at the junction of the two. A line of trenches and holes, over 600 yards long, has been made in a south-westerly direction from the shaft, and exposes many interesting rocks. The hole furthest from the shaft which shows rock other than surface limestone, is in rotten granite, then comes a band of sheared lava with amygdales of quartz and epidote; a slice (2049) from one of the more solid lumps in this rock is made of quartz, felspar, very pale actinolite, epidote and granular sphene; the felspar is in small quantity and appears to be the remnant of the original mineral, it often shows strain effects, but is without definite shape; the quartz is to a great extent in the form of mosaic; the epidote is in grains often associated with quartz in lath-shaped areas representing original felspar; the actinolite forms ragged plates and needles. In ordinary light the numerous pseudomorphs after felspar give the rock the appearance of a little altered lava, but between crossed Nicols the field is broken up into small quartz and felspar areas, obliterating the shape of the pseudomorphs. This belt of lava is over 20 yards wide, and is succeeded north-eastwards by a sand belt 50 yards wide, in which the prospecting holes are filled up, though fragments of both granite and green lava lie round them. Some lava is exposed in a hole just beyond the drift sand, and granite 10 yards further on. A section (2050)

through this granite shows that it is a coarse rock made of quartz, microcline, albite, muscovite and chloritised biotite, and that it has been crushed; in parts of the slide fragments of quartz and felspar lie in a fine-grained matrix in which sericite has developed. The next pit, 8 yards further on, is in a grey slaty rock with dark elliptical patches in it representing amygdales. This rock is seen in thin section (2051) to be made of oligoclase-andesine felspar, of which a few almost unaltered lath-shaped sections are visible as well as the remains of others, very pale actinolite, quartz in the groundmass and granular sphene. The actinolite is in small ragged plates and needles throughout the slice; 20 yards nearer the shaft, crushed granite is again seen, followed by rather over 100 yards of green schistose rock with bands of flattened amygdales, which are succeeded by 160 yards of crushed granite with veins of pegmatite. A slice from a specimen of this granite (2052) happens to be taken from a part that shows more completely the effects of crushing than slice (2050). No altered or fresh biotite is visible in this rock, and there is some epidote, and there is much sericite in a fine-grained colourless matrix which encloses fragments of quartz and felspar crystals; there is also a fair amount of rather large-grained quartz mosaic. At the north-eastern side of this belt there is a mixture of granite and green schist in the form of a schistose breccia, which is seen under the microscope (2047) to have a fine-grained matrix of colourless minerals, probably quartz and felspar, some sericite and much chlorite enclosing fragments of felspar and quartz. Then follow 80 yards of green schist, 50 yards of granite with bands of crushed rock in it, and 160 yards of sheared amygdaloid and green schist traversed by quartz veins lie between it and the shaft. The quartz veins run parallel to the schistose planes and the direction of the granite junctions (W. 20° N.) exposed in the cuttings. The junctions are evidently fault planes, and the repetitions of granite and lava bands due to faulting. North-east of the shaft the cuttings are continued for some yards in sheared amygdaloid. In this part of the cuttings there is a good series of sheared lavas and very fine-grained slaty rocks. The lavas vary from rocks that have suffered little change, and contain the usual rounded amygdales of quartz, or quartz chalcedony and epidote, to rocks with a well-developed cleavage and dark oval patches, which show schistose structure very markedly; the dark mineral gives the peculiar dark blue interference colours which seem to be characteristic of the chloritic mineral delessite, and the large patches of it are evidently amygdales. In thin section (2046) the felspar, oligoclase, is very plentiful and mostly still fresh, though occasionally encroached upon by tremolite or very pale actinolite; the base of the rock is a very fine-grained aggregate of colourless minerals and grains of sphene; there is much tremo-

lite or actinolite, and several elongated streaks of chlorite or delessite are seen in the slice. The fine-grained slaty rocks are chlorite schists with fibres of tremolite; in their sections (528 and 529) they are seen to consist chiefly of chlorite with some tremolite and granular sphene; they are much more altered than the rocks showing amygdales, and were probably tuffs. A lava showing little trace of shearing near the N.E. end of the cuttings (2045) is made of fresh oligoclase crystals with ragged plates of tremolite and fine-grained colourless quartz-felspar groundmass between them; there are also a few grains of epidote of large size, but these are probably parts of amygdales; the amygdales cut through the middle are occupied by large epidote grains outside and delessite and calcite within. Between this locality and the Orange River there are numerous outcrops of the amygdaloidal lavas, in places considerably sheared, so that the amygdales are very much elongated. The lavas make a range of hills, scarped on the west side, between Schalk's Puts and Blink Fontein, in which the dip is about 20° towards the east; some bands are crowded with amygdales. A section from a lava on the high beacon hill common to Schalk's Puts and Blink Fontein (2101) shows much oligoclase in small crystals, and a few larger porphyritic crystals of andesine up to 1-10th inch long, in a groundmass of quartz and felspar, very pale actinolite fibres, calcite, epidote and granular sphene, with amygdales of epidote and calcite, A rock (532) from a place two miles east of this beacon, near the homestead of Potdans, the north-east part of Riet Fontein, is made of small oligoclase crystals in a groundmass of quartz, felspar, chlorite, granular sphene and some calcite, There is no actinolite nor any sign of augite or pseudomorphs after it. The amygdales are of chlorite and calcite.

North of Greeff's Puts house the boundary between the lavas and granite turns sharply round to the west; this bend is followed by the cleavage in the lavas and the crush-planes in the granite, and there are many veins of quartz parallel to the boundary in both the granite and the lavas. The veins make a line of prominent kopjes on Blink Fontein, Lot A; these are situated within the Ventersdorp beds. The junction with the granite is obscured by sand.

The whole of Blink Fontein, Lot B, and parts of Blaauw Puts (Kaboom) and Zeekoe Baart are occupied by greenish amygdaloids often much sheared, and green slaty rocks, probably cleaved tuffs. The strike of the cleavage varies greatly; towards the Orange River, on Blink Fontein, it is northerly, or between N.N.W. and N.N.E., on the south eastern part of Zeekoe Baart, it turns N.E., and in the central part of the farm E.N.E. It follows the strike of the intercalations of quartzite and limestone shown in Fig. 12.

South of the south-west end of Ezel Rand there is an outcrop-

of sheared conglomerate surrounded by sand in the amygdaloid area. The true relationship of this rock is difficult to decide, for it resembles to some extent the sheared conglomerates in the Matsap series of Ezel Rand, and those very similar conglomerates found in fairly large masses entirely surrounded by amygdaloidal lava at the south-west end of the range, and at Zeekoe Baart. The matrix of the conglomerate south of the south-west end of the range is greenish, and the inclusions are quartzites containing magnetite and red cherts or jaspers. In thin section (546-548) it is almost impossible to distinguish between the matrix and inclusions, for the slices do not pass through one of the red jasper pebbles; the minerals seen are quartz, epidote, magnetite, calcite, chlorite and a little felspar. The rock has a granulitic appearance in those parts chiefly made of quartz, but much of the epidote is collected in grains with quartz in elongated areas, which look as if they were once occupied by felspar. A pebble of magnetic quartzite is cut by one of the slices. The magnetite usually shows good faces.

The lavas stretch round the south-western end of Ezel Rand, and crop out between that hill and the Dwyka area on Ezel Klaauw. The junction with the Kheis beds is hidden.

A fault with W.N.W. trend cuts off the Matsap beds at the south-west end of Ezel Rand, and they strike against sheared green amygdaloidal lavas and slaty rocks; the latter have high westerly dips, but the strike varies from N.N.E. to N.E., with occasional greater twists. These rocks are just like, and certainly belong to the Ventersdorp group forming such a wide area to the east and north-east, but they contain masses of conglomerate, indistinguishable from that of the basal portion of the Matsap beds of Ezel Rand, and up to 200 yards in length. This longest band is 80 yards wide at one place, and is bent through nearly a right angle; one part strikes E.-W., and the other half S.S.W., the green amygdaloid is sheared parallel to the outline of the mass. It is probable that this block and the two rather smaller ones observed are parts of the Ezel Rand rock detached by faults from the parent mass.

On the eastern side of the south-west end of Ezel Rand sheared green slates and amygdaloids with high dips to north-west underlie the Matsap beds, which dip in the same direction but at a lower angle. These volcanic beds were followed along the mountain slopes as far as the southern end of a marked embayment, which is due to a fault traversing the Matsap beds in a southerly direction, and along which the base of that formation is thrust eastwards over higher beds through some 300 feet. The Ventersdorp beds are not continued in this embayment, but give place to limestone of the Campbell Rand series which extend W.S.W. from the Hay district across the Orange River. There is a fault along this junction, occa-

sionally marked by vein quartz, but the line is obscured by sand. The Ventersdorp beds probably lie in contact with the limestone for 6½ miles, but then quartzites of the Black Reef series intervene between the two, and the Ventersdorp beds are cut off from the river bank by the junction of another band of Black Reef quartzite with north-east strike. To the south-east of the latter there is an extension of the Campbell Rand, but the Ventersdorp beds stretch round the end of the quartzite and come into contact with the limestone along a fault cutting obliquely across the latter. A third quartzite band lies chiefly in limestone, but extends some 500 yards into the Ventersdorp beds, and the latter pass round it and come into contact with the limestone on the west and a fourth ridge of Black Reef quartzites on the east, which lies west of Consente Kraal, the south-east corner of Zeekoe Baart. The Ventersdorp beds over this large area are very much sheared, the quartz amygdales often form "eyes" round which the schistose planes bend, and the lava itself has a pronounced slaty character. When the steam-holes were filled with chlorite or calcite they have yielded to the pressure to a much greater extent than the quartz amygdales, and they appear in places as thin oval films along the cleavage planes.

The lavas extend round the southern end of the Consente Kraal ridge, and reach the river bank on the east side of its north end, but do not appear on the right bank of the river, A long tongue of limestone, with a few feet of quartzite below this, runs southwards from the river here with lavas and slates on each side, but it gets narrower and disappears near Consente Kraal house, and another ridge of quartzite forms the river bank for over a mile north of that house, separating the volcanic rocks from the river, but it also dies out in the volcanic rocks. A thin section (2107), cut perpendicular to the cleavage, through a sheared green amygdaloid between the eastern ridge on Consente Kraal and the limestone, shows that the cleavage is due to the parallel or wavy arrangement of chlorite flakes; a considerable amount of plagioclase still remains, and the other constituents are calcite, a little quartz, magnetite and granular sphene; no actinolite or tremolite is visible.

Opposite the south end of Consente Kraal the volcanic beds extend across the river on the farms Stilverlaats and Leelyks Staat, where they are succeeded eastwards by the Black Reef quartzites, but these cross the river on the latter farm, and are continued on Blink Fontein as two ridges separated by a band of volcanic beds and an included streak of limestone. These quartzites terminate southwards in the volcanic beds, but on the line of strike of the eastern band another rises from the volcanic beds on Potdans; it is entirely surrounded by the green volcanic rocks.

On the right bank of the river, opposite Potdans and

Schalk's Puts, the Ventersdorp beds form a narrow strip of country west of the Black Reef series, on O.322, and entirely surround a sharp foliated synclinal band of the quartzite now separated by denudation from the main area. On the same farm (O.322), near the sharp northward bend of the river below Koegas, the Black Reef beds, and also the Campbell Rand series, disappear at the surface owing to a thrust-fault which brings the Ventersdorp beds into contact with the Lower Griqua Town beds. The southern continuation of this boundary on the left bank of the river has already been described.

The lavas on Potdans and Blink Fontein are of the usual varieties, some without any amphibole others with tremolite or actinolite. The lavas near the quartzite ridges are more sheared than those further away. A thin section (2103) taken from a brownish-grey rock, with small irregular cavities in it, on the west side of the Blink Fontein ridge, shows that the rock has been considerably altered; it consists of felspar, chlorite, iron ores, and probably some quartz; the felspars are remnants, and except for pseudomorphs of haematite after magnetite, no sign of the original structure of the rock is visible. On Blink Fontein there are outcrops of a coarse crystalline limestone amongst the lavas about 800 yards north of the quartzite boundary. They are on a line parallel to the strike of the enclosing rocks. A lava near the easternmost quartzite on Potdans (2104) is a porphyritic rock with pseudomorphs up to ¾ inch long of alteration products after felspar; the mass of the rock is made of the remains of small felspars, chlorite, tremolite in short ragged pieces, a little quartz, calcite, sphene, leucoxene and epidote. A rock from the east side of the north end of the middle ridge on Potdans is very amygdaloidal, the holes being chiefly filled with calcite, with quartz and chlorite as subordinate materials; the matrix is but little changed; it consists of lath-shaped oligoclase in a base of colourless matter (felspar and quartz) containing minute chlorite flakes and dull leucoxene.

North of the rather wide belt of Campbell Rand limestone limiting the large area of Ventersdorp beds just described, there are two further areas of the latter which present a remarkably complex structure. (See Fig. 12.) The two northern areas are separated by a band of rock connected on the west with Ezel Rand and there made of Matsap beds alone, but on the right bank of the Orange River first limestones of the Campbell Rand series and then the Lower Griqua Town beds come in on the dip side of the Matsap strip, which thins out about two miles from the river, leaving the Ventersdorp areas separated only by the Griqua Town beds. The latter at first have an E.-W. strike, but they bend round through S.E. to S.S.E. and run into the large mass of the same beds on Stil-

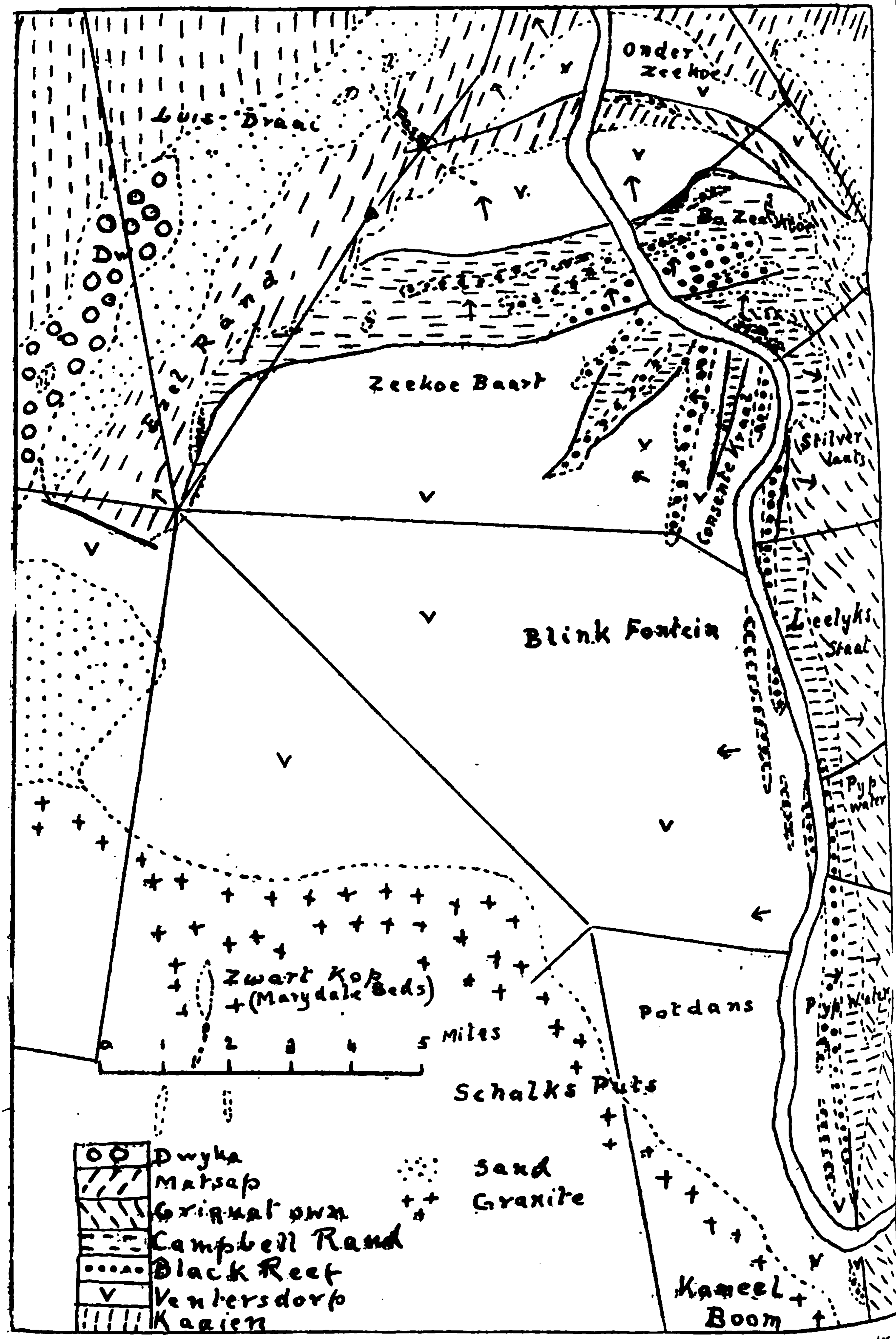



FIG. 12—Plan showing the structure of the Zeekoe Baarts, etc. (The southern farm called Pypwater should be O.322.)

verlaats. The northern area of Ventersdorp beds is arc-shaped, limited on the concave or southern side by the band of later rocks just described, and on the northern or convex side by Matsap beds.

Throughout these areas the dip of all the rocks are northerly, between N.W. and N.E., and the remarkable arrangement of the beds must be due to faulting, chiefly owing to thrusting from the north or north-west. This part of the district is further complicated by the intrusion of basic igneous rocks.

We will describe first the southern area of Ventersdorp beds, about $7\frac{1}{2}$ miles long from W.S.W. to E.N.E., and extending from under the Ezel Rand beacon hill through the farm Zeekoe Baart to Boven Zeekoe Baart. At the western end the green sheared amygdaloids and slaty beds without amygdales lie above the Campbell Rand limestones and dip at angles over 60° below the Matsap beds of the Beacon hill, which commence with sheared conglomerates. A typical specimen of the sheared green rock without amygdales, from the plain at the foot of the Beacon hill (2116), is seen under the microscope to be made of felspar, quartz, tremolite fibres, epidote grains and leucoxene. The outlines of the original felspar laths are visible by ordinary light in many parts of the slice, but they break up into aggregates between crossed Nicols; the rock is evidently a lava which has been considerably altered. In the western corner of the area no conglomerate bands were seen in the Ventersdorp beds, but north-east of the road to the Pass conglomerate bands with quartzite and ferruginous cherty or quartzitic boulders and a reddish matrix, exactly like conglomerates in the Matsap series itself, are met with in the lavas. Any one band cannot be traced further than a few hundred yards, usually only for a much shorter distance.

A section measured across the strike of the beds between the house on Zeekoe Baart and the river gave the following figures:—

| | Feet. |
|---|---|
| Green amygdaloid ... | |
| Compact greenish diabase (a lava) ... | 156 |
| Red amygdaloid ... | 69 |
| Compact green diabase (a lava) ... | 114 |
| Green amygdaloid ... | 42 |
| Conglomerate with red matrix (A) ... | 30 |
| Soft Slaty rocks ... | 69 |
| Sheared green amygdaloid ... | 111 |
| Conglomerate with red matrix (B) ... | 18 |
| (Hidden) ... | 66 |
| Conglomerate with red matrix (C) ... | 39 |
| (Hidden) ... | 90 |
| Red amygdaloid with streaks of green amygdaloid ... | 96 |

| | Feet. |
|---|---|
| Conglomerate with red matrix (D) ... ... ... ... | 30 |
| (Hidden) ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... | 42 |
| Red amygdaloid ... ... ... ... ... ... ... ... ... ... ... ... ... | 15 |
| (Hidden) ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... | 60 |
| Red lava ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... | 6 |
| *Matsap beds*:— | |
| Slate (blue-purple) with bands of pebbly conglomerate ... ... ... ... ... ... ... ... ... ... ... ... ... | 69 |
| Schistose grits (purplish in colour) ... ... ... ... | 129 |
| Conglomerate with red matrix, disappearing at short intervals by being squeezed out ... ... ... | 1 |
| Schistose grit... ... ... ... ... ... ... ... ... ... ... ... ... | 51 |
| Greenish and red amygdaloid ... ... ... ... ... ... | 6 |
| Schistose grits ... ... ... ... ... ... ... ... ... ... ... ... | 450 |
| Schistose grits with three bands of red conglomerate (E) ... ... ... ... ... ... ... ... ... ... ... ... | 88 |
| (Hidden) ... ... ... ... ... ... ... ... ... ... ... ... ... ... | 108 |
| Schistose grit ... ... ... ... ... ... ... ... ... ... ... ... | 51 |
| (Hidden; schistose grits to S.W.) ... ... ... ... ... | 592 |
| Schistose grits ... ... ... ... ... ... ... ... ... ... ... ... | 100 |
| Red conglomerate (F) ... ... ... ... ... ... ... ... ... | 12 |
| Schistose grits above which no further conglomerates or lava was seen. | |

Just as the conglomerate beds in the green rocks disappear within short distances, so do the lavas in the purplish schistose grits of the Matsap series. The intermingling of characteristic rocks of the two series is almost certainly due to folding and faulting.

A red specimen from the 6 feet of amygdaloid found well up in the Matsap grits is seen in thin section (2108) to consist of quartz, magnetite, haematite, epidote, calcite and chlorite, with possibly a little felspar. Quartz forms the basis of the rock and occurs as a rather fine-grained mosaic in which lie irregular grains of the other constituents and innumerable minute particles of iron ore often aggregated to form small patches. A distinct shearing structure is visible, but where this is less marked than usual clear pseudomorphs of quartz and epidote after felspar crystals can be seen. The amygdales, some of them drawn out parallel to the schistose planes, are of quartz, epidote, calcite, and chlorite in flakes associated with the quartz and calcite but not with epidote. A section from a very similar-looking rock from one of the red amygdaloid beds amongst the Ventersdorp series (2115) south-east of the farmhouse on Zeekoe-Baart proves to be a fragmental rock including pieces of lava with amygdales. The slice was obtained for the purpose of comparing this rock and the one described above, and is the only other slice of one of the red

volcanic rocks. Although no strict comparison is possible, the two rocks are much alike, the chief difference being due to the presence of obviously detrital grains of quartz in (2115) and some unaltered felspar; in other respects it is like (2108). The iron ore in these rocks seems to have been introduced, for the usual lavas in the neighbourhood are without it, and there are several places where the transition from the red to the green rock in one and the same bed was seen in the field. The appearance of the iron ore in these red lavas is just like that of the iron ore in the red conglomerates (A—F) in the measured section.

These conglomerates will be described under the Matsap series; it is only necessary to point out that the bands A—D in the section may well be repeated outcrops of one band; in each case the conglomerate is underlain by lava. It is not unlikely that the repeated band is the basal bed of the Matsap series.

The occurrence of conglomerates like those of the Matsap beds in the lavas near the south-west end of Ezel Rand has been described above. The only other place where they have been noted is near the limestone belt in the middle of the southern edge of this area of Ventersdorp beds. The conglomerate at that place has a hard ferruginous cherty matrix containing lumps of haematite and magnetic jasper and epidotised lavas. This rock is probably part of the Matsap series. It only occurs in a few outcrops, and there is uncertainty as to what immediately underlies it; it is followed northwards by lavas in which there is an intrusion of diabase.

The green amygdaloidal lavas vary somewhat in character in this area, but they all contain much epidote. A much-sheared rock with epidote and chlorite amygdales from close under the mountain west of Zeekoe Baart house (2117) is seen under the microscope to be a very fine-grained mixture of quartz, epidote, chlorite and a little magnetite; neither felspar nor tremolite or actinolite is visible; the quartz forms a small but even-grained mosaic, the epidote and chlorite irregular plates of very small size and mostly lying in one plane, and the magnetite is in minute anhedral grains.

Some of the rocks are pale or bright green in colour, with quartz amygdales. Under the microscope these rocks (544 and 545) are seen to be made entirely of quartz and epidote together with a little granular sphene. No traces of pseudomorphs after felspar are visible, and the amygdales are the only evidence of the original nature of the rock. Other rocks are equally dependent on the amygdales for evidence of their original structure, but the colour is darker; in thin section (538, 539) they show chlorite, calcite and tremolite in addition to quartz, epidote and sphene. The chlorite is in small flakes distributed throughout the slices, and small fibres of tremolite are also widely distributed. The quartz and epidote are in

much smaller amount. There are rocks intermediate between these two kinds; a thin section of one of them (537) shows a considerable amount of epidote and quartz with a little tremolite and chlorite; the epidote and quartz are in quite irregularly-shaped areas, and the original structures have been obliterated with the exception of amygdales, as in the series previously described. In another rock from the same neighbourhood (540) the original structure is in part preserved, felspars of the oligoclase-andesine series being abundant though in process of replacement by quartz, epidote, tremolite and chlorite. Parts of the slice are just like the epidote-quartz-tremolite rocks mentioned above. Leucoxene and sphene are also present.

A rock from Onder Zeekoe Baart, on the right bank of the river, taken to be a volcanic breccia in the field, is seen under the microscope (2201) to have lost its original character and to be made of secondary minerals, quartz and epidote chiefly, with some calcite, magnetite and haematite.

The northern area of Ventersdorp bed is rather smaller than the southern one, but is similarly-shaped, and is made of similar rock, though intrusions, some sheared and others unsheared, are more frequent in it. On the left bank of the river the green lavas and slates abut against the Matsap beds along the southern boundary fault, which is continued in a W.S.W. direction into the Ezel Rand itself, and along it the Ventersdorp beds are again exposed in the heart of that range where it is deeply cut into by the stream bed from Louis Draai. These outcrops are seen for short distances in the ravines on each side of the road through the Pass, but the rocks are entirely covered by the Matsap beds on the mountain slopes; they are sheared green rocks with occasional lenticles of less sheared rock retaining amygdaloidal structure.

On the right bank of the Orange River the Ventersdorp beds of the northern area occupy a wide space on Onder and Boven Zeekoe Baart, but they do not seem to occur on Zeekoe Baart's Nek or O.312; there is much sand on these farms and on O.303, and the underlying rock is not known.

## THE TRANSVAAL SYSTEM.

Rocks belonging to this system were only recognised in the Doornbergen and the country immediately south-west of that range, and along both sides of the Orange River from Prieska to the Ezel Rand.

As in Griqualand West and Bechuanaland this system is divisible in Prieska into three groups, the Black Reef, Campbell Rand, and Griqua Town beds. The relation of the three groups is not so obvious as in the country north of the river, because this area has been disturbed to a very much greater degree in pre-Dwyka times than the latter.

An account of the structural features is given in the first part of this Report, so here only the details of each group need be mentioned.

## THE BLACK REEF SERIES.

In this district no conglomerates were seen in the Black Reef series; it consists of quartzites, often false-bedded and ripple marked, limestones and calcareous grits. The quartzites, even in the most disturbed areas, do not often show the effects of the pressure and shearing in a hand specimen; usually the larger grains are distinctly visible, though under the microscope the grains show strain shadows between crossed Nicols. The frequent cross bedding and ripple marks as well as the visibility of the grains give the Black Reef quartzites a different appearance from those of the Kaaien beds, and sericite is but slightly developed in the former. A thin section of a folded quartzite (662) from near the Uitspansberg-Prieska Poort boundary shows the results of intense shearing; the original grains are not visible, though their remains may be represented by small fragments of quartz and felspar surrounded by a micro-crystalline matrix with schistose structure, to which scattered but very small flakes of chlorite and pale brown biotite give added effect. This rock comes from a place where the Campbell Rand group is absent, and some quartzites alone intervene between the Griqua Town beds and the granite. It may possibly belong to the Kheis group brought up along a fault which certainly exists here. Where the western line of Uitspansberg crosses the Black Reef there are two masses of quartzite in contact, that on the north-east shows the usual characters of the Black Reef series in this area, while the south-western mass, which is forked, is a sericitic quartz-schist; there seems to be no intermingling of the two, and it is probable that the latter belongs to the Kheis series. Elsewhere there was never any doubt as to which group the quartzitic rocks should be placed on lithological grounds alone.

A rather characteristic variety of quartzite in this area is distinguished by spherical patches of a rusty colour and up to half an inch in diameter. In thin section (2036) these patches are seen to be due to the presence of magnetite and hydrous oxides of iron taking the place of the usual siliceous cement between the quartz grains. These spotted quartzites were met with at many places between Uitspansberg and the isolated bars of quartzite on the Zeekoe Baarts.

Though conglomerates were not found, the quartzites of the hills between Wit Fontein, Wit Vley, Nauga, and Kalk Gat contain a few scattered angular fragments of black slaty rock. A section through such a rock from Wit Vley (2176) shows that the quartzite contains some felspar and tourmaline in small fragments, and also that the black pebbles are a tourmaline-quartz-zircon rock crowded with thin prisms of pale brown tourmaline.

Where clear sections through the base of the series can be

seen, as on Nauga, Wit Vley, and Westerberg, the lowest beds are calcareous grits, with some quartzites, and these are succeeded by limestone,[1] which may be 40 or 50 feet thick, and then comes the main mass of quartzite, perhaps with calcareous grits near the limestone. One of the grits from Wit Vley has been cut, (2173); it is made of rounded grains of quartz up to 2 mm. in diameter, with a few equally large grains of microcline, embedded in a matrix of small angular grains of quartz and felspar, some siliceous and much calcareous cement; the grains are much strained. In the Wit Vley limestone a process of silicification has taken place from the joint surfaces inwards; in some cases the thickness of the white cherty rock, which is the final result, is three inches thick; the transition stages from such a rock to blue limestone only occupy half an inch or less. Where the limestone contains rounded quartz grains these keep their character in the chert, and give it a superficial resemblance to a quartz-felsite with rounded quartzes.

A thin section of a grit from the lenticular patch of Black Reef beds on Westerberg (2037) is made of round quartz grains up to 1 mm. in diameter, set in a matrix of small chips of quartz with a cement of silica and a greenish substance.

## THE CAMPBELL RAND SERIES.

These beds occur in two distinct areas, a small anticlinal area about $10\frac{1}{2}$ miles long from north to south by 5 wide traversed by the Orange River below Prieska, and in a long irregular belt on the south-west side of the Doornbergen and the Koegas hills. In the first-named area the limestones are to a large extent covered by outliers of the Dwyka, especially on the left bank of the river; the dips in this area are low. In the second the dips are high, and the series often disappears at the surface for considerable distances owing to faulting. The limestones are very much folded on a small scale in the anticlinal tongue, with south-east pitch between the Uitspansberg ridge and the Rooi Hoogte-Middel Water hills; they are well exposed on the low hills on Kalk Kat and Klip Fontein, where the outcrops of limestones and interbedded cherts make zig-zag curves and many sharp synclines and anticlines with less steeply-pitched axes. An occasional section, such as that shown in Fig. 13, drawn to scale from a cliff on the left bank of the ravine on Pypwater, shows clearly the intricate type of folding.

In lithological character the beds of the Campbell Rand series in this area are similar to those described in the Reports for the years 1905-1907 from the country north of the Orange River. Dolomitic limestones are the predominant rocks; they frequently contain chert, and beds of shale are occasionally met with. On

---

[1] An analysis of a specimen from Wit Vley by Prof. van der Riet, of Stellenbosch, shows that it contains 35·6 % of $CaCO_3$, 23·0 of $MgCO_3$ and 7·47 of $FeCO_3$.

Klip Fontein and Kalk Fontein there are blue mudstones with large crystals of pyrites. Quartzites occur on Kalk Fontein near the top of the series, on the eastern side of the anticline, but similar beds were not seen on the western side under the Uitspansberg ridge; they are 10 feet thick. Several masses of

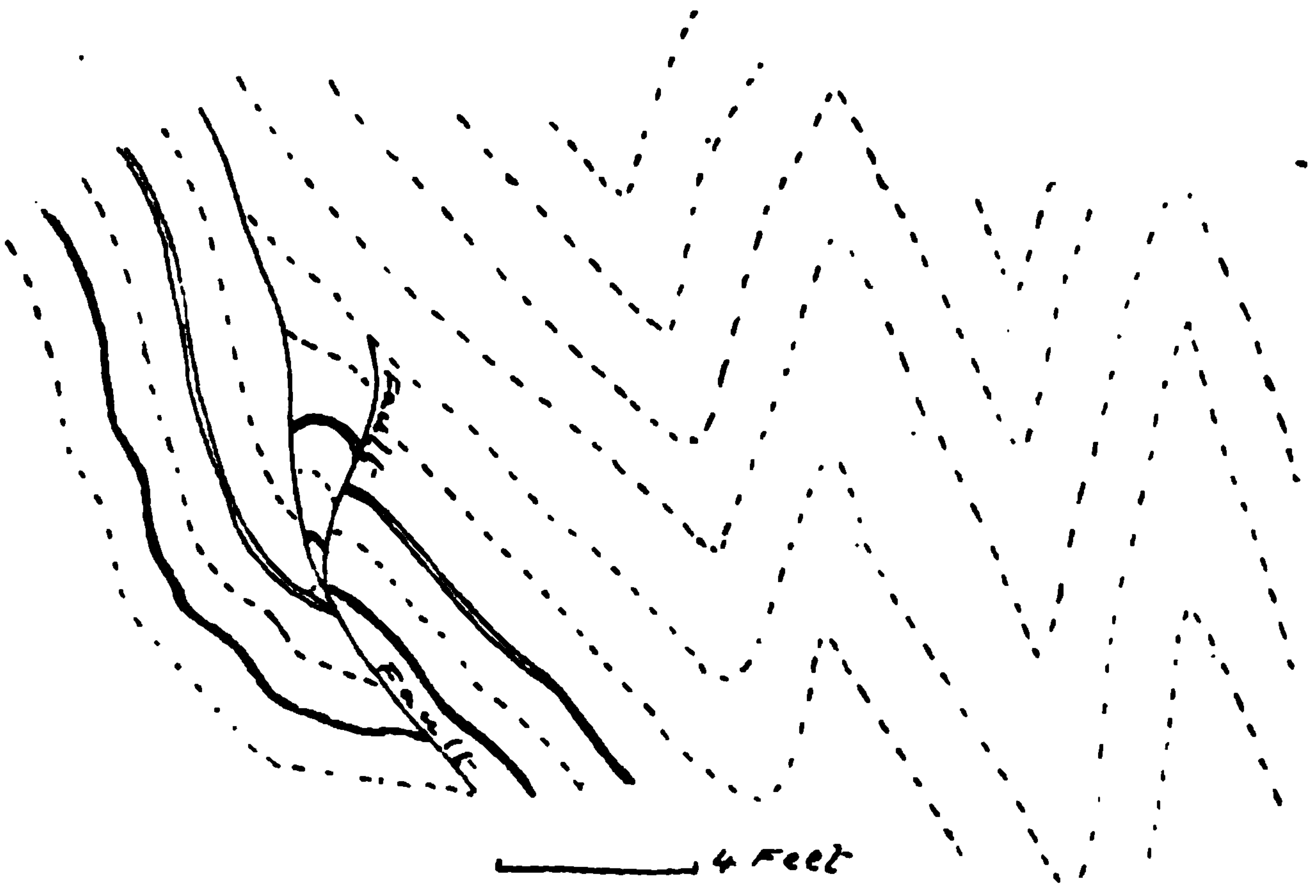



FIG. 13.—Folds and Faults in limestone on left bank of ravine Pypwater. The dark band and the double lines represent bands of chert. The dotted lines are bed planes in limestone.

quartzite, entirely surrounded by limestone, were found on Kalk Gat and Nauga, but three of them are certainly anticlinal inliers of the Black Reef series, for they include quartzites with rusty patches similar to those in the Black Reef on the south-western flank of the area.

In the inliers between Omdraais Vlei and Zoet Vlei there is a good deal of dark red chert passing into jasper in the limestone, more especially in the upper horizons of the formation.

On Zeekoe Baart red and black banded jaspers are interbedded with the limestones. Some bands of these rocks are as much as a foot thick, and were traced 60 yards before they thinned out.

Three analyses of Campbell Rand limestones lately made by Prof. Van der Riet gave the following percentages of carbonates:—

| | | $CaCO_3$ | $MgCO_3$ | $FeCO_3$ |
|---|---|---|---|---|
| 1. (from Postmasburg) | ... | 54·09 | 42·35 | ·7 |
| 2. (from M. 84 Hay) | ... | 54·37 | 30·47 (including $MnCO_3$) | 9·2 |
| 3. (from Zeekoe Baart) | ... | 50·19 | 27·73 | — |

## THE GRIQUA TOWN SERIES.

The Lower and Middle (Ongeluk) beds of the Griqua Town series are found in the district.

### *The Lower Griqua Town Beds.*

Rocks belonging to this group make almost the whole of the Doornbergen and the hills on the right bank of the Orange River above the Zeekoe Baarts.

There is nothing of a general nature to add to the descriptions of the lithological features of the group as given in the Annual Reports for 1905-8, though some additional details can be mentioned.

On the north side of the Orange River some remarkable rocks occur on a horizon some few hundred feet above the base of the series on the farms Wilgebooms Dam and Engelde Wilgeboom. They are cherts with many layers of magnetite, and they contain long slender prisms of a dark blue hornblende; it is a different substance from crocidolite, which is abundant in the neighbourhood on nearly the same horizon, for it is not fibrous and has different optical properties. Under the microscope (2192-5) the prisms are seen to be bounded by prism and clinopinacoid faces. The extinction angle is small, probably less than 5°, but owing to very strong dispersion and the deep colour the position cannot be determined easily by the use of white light. The mineral is very strongly pleochroic (X indigo-blue, Y grey-blue, Z yellow). In the magnetite layers there is also some crocidolite in very slender fibres. In some layers the blue hornblende is so abundant that the rock appears to be made entirely of it, but there is always a cherty matrix. The arrangement of the crystals varies; in places they are scattered promiscuously through the chert, but often a large number of them lie in one direction inclined about 30° to the bedding planes. In the same neighbourhood yet another variety of amphibole occurs in star-shaped bunches up to two inches in diameter lying in the bedding planes of the rock (ferruginous cherts). The mineral is very pale coloured. It was only found in fragments in the precipitous kloof west of Wilgebooms Dam homestead.

A section (2023) cut from a heavy blue rock on Middel Water shows that it is a felted mass of short crocidolite fibres with a few very small specks of chert and some small yellow patches due to incipient alterations of the crocidolite. This rock forms thin layers separated by similar material with the addition of magnetite. On Prieska Commonage near the river 2 miles below the village crocidolite occurs in a ferruginous limestone (2022).

The beacon common to Prieska Poort and Keikams Poort is situated on a peaked hill, in which the most prominent band is formed by a thick bed of a tough green rock flanked by dark blue crocidolite bearing rocks and banded ironstones. The rock is composed of grass green pyroxene in large crystals with a small amount of oxidised pyrites and little limonite. The specific gravity of a specimen is 3.43.

A thin section (1975) shows a mineral with faint pleochroism, high negative double refraction and high dispersion, cleavages at

right angles and extinction as high as 12°. It appears therefore to belong to the aegirine-augite group, but no analysis has been made to decide this point.

On Prieska Poort there are many varieties of dark green rocks exposed close to the dam and varying from quartzites on the one hand to slates or chloritic schists on the other. The peculiar little isolated black kopje alongside the dam is formed of banded ironstone, with a core of green phyllite passing downwards into a coarse arkose. The latter appears again below the outcrop of the prominent band of limestone forming the outermost chain of hills in which the Griqua Town beds appear. The phyllites here contain little lenticles of grit, limestone, chert, ferruginous quartzite, and sometimes arkose. These lenticles may swell out in places to form beds of quartzite, limestone, or banded ironstone, which may die out again within a short distance.

The greater part of the Lower Griqua Town series in this area is banded magnetite, limonite, or haematite cherts or jaspers; but where the shearing has been intense, as in the arc-shaped strip of these beds on Boven and Onder Zeekoe Baart, and the shorter strips on O.312, Boven Zeekoe Baart and Zeekoe Baart, they are converted into lustrous haematite schists.

Towards the top of the group sandstones are seen some 200 feet below the base of the Ongeluk lavas round the southern end of the Abram's Dam syncline on Hoogans, Kameel Fontein, Naragas, Kloof Fontein, Folmink, Bult Fontein, Jans Plaats, and Swaart Pan, and in analgous positions round the southern ends of the Paarde Vley and Leelyks Dam synclines. They are dark blue or greenish rocks; a thin section (2196) from Kameel Fontein shows small angular grains and chips of quartz and plagioclase set in a matrix of chert, calcite, and chlorite; the calcite is also in the form of grains, as if it were debris from a crystalline limestone. Near the Kameel Fontein beacon hill (a large beacon stands on the very prominent kop on the Ongeluk escarpment) these sandstones are over 20 feet thick; elsewhere they are much thinner.

Between these sandstones and the glacial beds there are shaly beds and limestones. At Kameel Fontein the limestones are very thin, two or three feet seen occasionally at the foot of the Ongeluk escarpment, and the glacial beds are at least 30 feet thick, probably considerably thicker; on the south-west side of the syncline, on Blaauwbosch Fontein and Folmink, the limestone is at least 20 feet thick, while the glacial beds are only from 5-15 feet thick. On Koegas Puts the limestone is 150 feet thick, and the glacial beds always less than 10 feet. The glacial beds in this area are not much altered, the matrix is blue in colour and contains much calcite; it closely resembles the matrix of the tillite of Good Hope (Barkly West) and Kort Kloof Fontein (Hay.)[1] Two thin sections (2198) from Koegas Puts and

[1] Ann. Rep. Geol. Com. for 1906, pp. 34-5.

(2200) from Jans Plaats, show substantially the same characters; in a matrix of cherty silica, carbonates, and a greenish substance lie chips and grains of quartz, plagioclase felspar, chert, limestone, and a few chloritised mica flakes. Typically striated pebbles and boulders were found in all the good exposures. The beds between the tillite and the Ongeluk lavas are not often exposed. On Kameel Fontein there is room for a few feet of them; on Folmink they are under 2 feet thick, and on Koegas Puts from 4 to 6 feet of greenish-brown shale lie between the two rocks. A thin section of the Koegas Puts shale (2223) is seen under the microscope to consist of chips and grains of quartz in a green matrix made of fine cherty material with much chloritic matter.

The glacial beds were not found in the syncline containing an outlier of the Ongeluk beds on Uitspansberg and Glenallen, but as the lavas crop out along the bottom of a steep-sided valley and are themselves to a great extent concealed under debris, the fact does not prove that the glacial beds do not exist there. Limestones in the Lower Griqua Town beds were seen on either side of the Ongeluk beds on the slopes of the hills, so it is probable that the succession of the beds in fairly complete on each side, though both limbs dip south-west, and that there is no fault of importance at the junction.

### *The Ongeluk Beds.*

The lavas of the Ongeluk group occur in overturned synclines on the south-west flank of the Doornbergen near Uitspansberg, and again south of Keikams Poort; in each case the outcrops are in all about two miles long in the direction of the strike of the beds, and much narrower across the strike. In addition to proving the southward extension of this volcanic group across the river from Griqualand West, these occurrences are of importance in indicating the structure of the range as a whole (see Fig. 14).

The northern outcrops are traversed by the boundary between Uitspansberg and Glenallen, and they lie at the bottom of a well-defined longitudinal valley which still retains traces of the former infilling of Dwyka. They are bluish lavas showing the usual pilotaxitic structure characteristic of the Ongeluk lavas, and they are amygdaloidal in places. Two thin sections (2216 and 2217) have been cut from this locality; in the latter the felspars are fresh, both small well-developed crystals and microlites of plagioclase are present; the other constituents are feathery, ill-defined hornblende and a devitrified base. On Keikam's Poort the base of the formation is concealed by sand, then comes a considerable thickness of lavas, showing the structures characteristic of this formation and containing enstatite, and after that a couple of hundred feet of volcanic breccia dipping westwards at a high angle. The breccia contains fragments up to a foot across of various types of lavas. To the

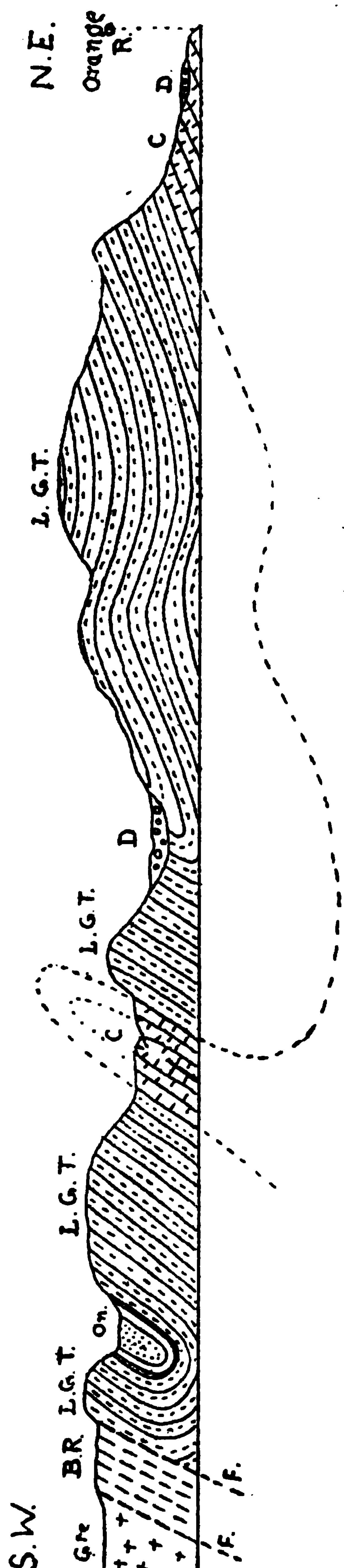



FIG. 14.—Section through the Doornbergen, near Glenallen (the homestead stands on the Dwyka in the middle of section), to show the nature of the folding, the Ongeluk syncline, and the boundary faults on the south-west. Gte., granitic gneiss; B.R., Black Reef; C., Campbell Rand series; L.G.T., Lower Griqua Town beds; On., Ongeluk beds; D., Dwyka; F., faults (thrusts). The length of the section is about 11¼ miles. The vertical scale is exaggerated 10 times.

west there are several hundred yards of sand-covered ground before the Griqua Town beds reappear.

The areas occupied by the Ongeluk lavas north of the Orange River examined during last season were the southern ends of the Abram's Dam, Paarde Vley, and Leelyks Dam synclines, the greater part of which were described in the Report for 1905. The rocks seen showed no new features.

## THE MATSAP SERIES.

These beds were seen in the extreme south-western end of the Langebergen (Witberg and the range at Zeekoe Baarts Nek) and the continuation of the western fork of the Langebergen called Ezel Rand, on the left bank of the Orange River; a few outliers of the series lie in the fork on Piljaar's Poort and O.315.

The Ezel Rand beds were described in the Report for 1899, p. 82, but a further account of them is given here, because the structure of the area is not what it was then taken to be, owing to the recognition of the Zeekoe Baart amygdaloid as part of the Ventersdorp system.

On a previous page a measured section through the base of the Matsap group near the river is detailed. It is very probable

Kheis beds have been thrust towards the S.E. or E.S.E. At the extreme south-western end of Ezel Rand the Ventersdorp beds appear directly behind the Matsap beds, but they were not found in situ for more than a mile in that position, and they end in a tongue-shaped area between the Dwyka and sand. At Luis Draai and across the river the Kaaien beds are the only pre-Dwyka rocks seen behind the Matsap ranges.

## Intrusive Rocks of various kinds older than the Dwyka.

The granites and some other intrusive rocks older than the Ventersdorp formation have been described previously. There remain several intrusions of intermediate and basic composition, older than the Karroo system, but whether some of them are younger or older than the Matsap beds is not certain, though others are younger.

On Zeekoe Baart and Onder Zeekoe Baart there are three rather large intrusions of a diabase with remarkably large ophitic patches of augite which are conspicuous on a freshly broken fragment of the rock. In thin section (535, 536, 2109) the felspar is seen to be almost entirely changed to cloudy semi-opaque substances; the augite is usually fresh, but there is much chlorite and a little uralitic hornblende which seem to have developed at the expense of augite; some dark-brown or reddish biotite is present, and also quartz and ilmenite. A rather remarkable feature in this rock is that epidote is present in extremely small quantities only, a point of contrast to the results of partial alteration in the older diabasic rocks of Prieska. These diabases traverse the Ventersdorp beds on the Zeekoe Baarts. On Westerberg, Nauga, Koegas and neighbouring farms there are many sheets and dykes of diabase with characters like those of the Zeekoe Baart rocks. A thin section (2039) of one of them on Westerberg shows ophitic masses of augite, felspar, a little brown mica, quartz intergrown with felspar, and ilmenite. The felspar is almost all altered in a similar manner to that mineral in the Zeekoe Baart diabase, and there is no epidote, though chlorite and uralitic hornblende are both present.

These diabases have not been affected by the earth movements which disturbed the Matsap beds and the Griqua Town beds in their vicinity, so they are very probably younger than the Matsap series.

Along the south-eastern side of the eastern fork of the Matsap beds on Zeekoe Baart there is a sheared intrusion of diabase. In thin section (2110) it is seen to be made almost entirely of quartz and epidote, with small quantities of ilmenite and its alteration products, and chlorite. The quartz is evidently largely an original constituent, though now in part granulitised by pressure. The epidote is in grains and occupies, along with quartz and chlorite, areas that have the shape of felspar crystals.

In the Ventersdorp beds of Potdans and Blink Fontein there are intrusions of diabase of doubtful age. One of them (2102) is seen in thin section to be chiefly made of felspars, small porphyritic crystals of oligoclase-andesine felspar set in a fine-grained matrix of felspar, chlorite and carbonates. This rock is more like some of the Pniel lavas than any other igneous rock in the district, but it is seen to break across the amygdaloidal lavas in the field, and therefore must be intrusive.

On Westerberg there is a peculiar sheet of dark grey igneous rock interbedded with the Lower Griqua Town beds; in thin section (2202) it is seen to be a much altered rock made of tremolite, talc, some serpentine and a few ragged flakes of brown mica, pyrites and magnetite. The original nature of the rock is uncertain.

In the long granite area of the middle of Prieska district there are many altered diabasic rocks, some of which are hornblende-schists. Several of these have been mentioned under the Marydale beds, to the igneous rocks of which group they have a close resemblance. In many cases these rocks are older than the granite, for they are veined by that rock; in others, however, they may possibly be intrusive in the granite. The serpentines cutting the Marydale beds at Zwart Kop and near Uitspanberg have already been described. The belt between Jackals Water and Prieska Poort consists of a serpentine which from the section (678) was probably an olivine-enstatite rock originally. Serpentine with "grating" structure, has been developed from both of these minerals.

At Zoet Vlei there are serpentines which have probably been derived from olivine bearing rocks (700-4), but they now contain an abundance of needles and plates of tremolite. The rock may pass into a tremolite-schist (705), and there are veins in which finely fibrous white tremolite has been formed, accompanied by some green actinolite. These veins have been prospected under the impression that the mineral was asbestos.

On Blaauw Puts there are outcrops of serpentine in the gneiss, but the relation of the two rocks is not known. A thin section (2121) shows that the rock is made of serpentine, talc and magnetite, but no indication of the shapes of crystals of unaltered mineral could be detected.

Along the western side of the Doornberg there are a number of intrusions of pink syenite, usually in the form of thin dykes intruded along the strike of the beds in the westernmost chain of Griqua Town jaspers. In the southern corner of Prieska Poort in the open ground between this chain and the main mass of jaspers there is a large outcrop of red syenite, probably fully 250 yards across, and the rock weathers into great round masses like a granite, but differs from the granite outside Prieska Poort in being massive and not foliated; portions are traversed by veins of a red-black cherty material. On the north-east side the syenite is in contact with a small area of Black Reef

quartzites, the intrusive junctions being exposed at several points; the boundaries elsewhere are concealed either by Dwyka or by rubble and boulders. It is very probable that the syenite has a plug-like habit and fills a volcanic neck. Firstly, the position of the patch of Black Reef in the midst of the Griqua Town beds is difficult to explain in any other way; secondly, there are some peculiar dark-coloured and very decomposed igneous rocks, probably lavas, associated with it, and also a mass of limestone-chert breccia; thirdly, the rock itself under the microscope exhibits in places a brecciaform structure.

A thin section of the rock (2257) proves it to be composed almost entirely of slightly clouded orthoclase and microperthite, with a small amount of biotite now altered to chlorite, some magnetite and apatite, with a single grain of colourless augite. Calcite has developed in various portions of the felspar crystals.

Another section (2258) shows a fine-grained breccia of fragments of syenite like that in (2257), with a few angular pieces of quartz. A dyke close to the south-west corner beacon of Keikams Poort (2004) is practically a felspar rock; this mineral shows a peculiar lamellar inter-growth with another variety of felspar, and contains minute blebs of quartz, and may either be orthoclase or possibly anorthoclase.

A section of a pink dyke under the western beacon of the same farm shows (2003) porphyritic felspars set in an extremely fine-grained mass of irregularly interlocking felspar, with some quartz, yellow mica, iron ore, and abundant ochreous pseudomorphs after a carbonate.

A dyke from a point near the boundary between Prieska Poort and Uitspanberg is a dark reddish-brown rock, which is found in section (660) to contain crystals of orthoclase and oligoclase set in an extremely fine granophyric basic. As in the other rocks, there is some chlorite in irregular patches and some small grains of iron ore.

The age of this set of syenitic intrusions cannot be closely fixed. They are obviously post-Griqua Town, and as the main mass does not seem to have been crushed, the date of the intrusion may be later than that of the Doornberg folding. The rocks are certainly pre-Karroo, however.

At Prieska Poort, close to the dam and in the green slaty rocks under the ridge to the north of the road, there are peculiar irregular veins, composed of pink orthoclase felspar with a little quartz and siderite. They are in places several inches wide, but usually die out within a distance of a few yards. They recall the veins in the dolomites to which attention was drawn in the Report for 1899 (p. 78). These veins are irregularly distributed in the dolomite on the left bank of the Orange River on Zeekoe Baart; some are as much as an inch thick, but most are under half an inch. The quartz is a milky white variety like that of many veins in the older rocks, and in thin section (533-4, 2106) is seen to be crowded with gas and liquid

inclusions; the felspar is pink orthoclase. There are no intrusions in the neighbourhood, and it seems not unlikely that the minerals in these veins have been deposited by water in cracks independently of any phase of igneous activity, and that they are an example of quartz-felspar infiltration veins. It is not impossible, however, that they may bear the same relationship to the syenite dykes as the quartz and felspar veins in the Marydale beds do to the granite intrusive in the latter.

## The Dwyka Series.

As in the area to the north-east, this formation can be separated into a lower division characterized by boulder beds, and an upper division composed of shales. The boulder beds cover a wide belt of country stretching westwards from Omdraai's Vlei to past Van Wyk's Vlei. Inliers of the older formations become more and more numerous towards the north, and, speaking roughly, these old rocks make nearly continuous outcrops in a northerly direction from about the thirtieth parallel of latitude. Here and there are small outliers of boulder beds, but wide tracts are sometimes covered with boulders, relics left after the removal of the matrix; and in many places, where tufa and sand are present and the covering Dwyka is thin, it is difficult indeed to map the geological lines without excessive generalisation.

*Surface upon which the Formation rests.*—The floor upon which the Dwyka rests unconformably is very undulating and uneven. In the northern portion of this area the Dwyka tillite has been stripped from the older rocks, so that the present surface is almost the same as that of the old Karroo floor. In certain places denudation has removed much of the pre-Karroo formations; in others patches of tillite are still preserved in hollows and in valleys in the older rocks. Towards the south the cover becomes thicker, only the higher ridges of older rocks showing through the glacial deposits, until finally the entire floor is completely hidden by the younger formation.

The most important features in this pre-Karroo surface were the Doornbergen, the hills made of the Kaaien beds, and Ezel Rand, ranges which in places attain an altitude of over 4,000 feet above sea-level, or, roughly, from 500 to 1,000 feet above the surrounding country. The Dwyka wraps round the base of the southern portion of the Doornberg, and that part of the range shows remarkably smooth and graceful outlines in spite of the fact that the strata are intensely hard and usually tilted at high angles. The occurrence of patches of tillite in the longitudinal valleys of the Doornberg, for example, on Glenallen and Prieska Poort, and in some of the transverse valleys as well, make it extremely probable that only the minor features of this hilly country have been developed by post-Karroo erosion. The outliers on Piljaar's Poort, Dabep, Luis Draai, Ezel Klaauw, Karree Leegte, and Geelbosch Pan are strongly

confirmative of this view. West of the Doornbergen the ridges made of the Kheis series usually just fail to reach the 4,000 feet contour. In this area there are also many Dwyka inliers in the valleys on Jackals Water, Blaauwbosch Poortje, Spioen Kop, Saft Sit, Doonies Pan, etc., but over wide areas there is so much sand and tufa that the presence of this formation can only be suspected and not definitely proved. Further to the south, especially round about Drieling's Pan, Plat Sjambok, Jonker Water, and Klein Modder Fontein, the relative proportions of the areas occupied by the older and younger rocks are reversed, but the numerous little knobs of hard rock projecting through the flats of tillite only emphasize the rugged nature of the surface of which they form a part. As would be expected, the major valleys follow the strike of the Kheis series, and in certain cases have been excavated along the belts where soft mica-schist is the prevailing rock.

*Direction of Glaciation.*—Striated surfaces are rare, for the rocks tend to break up very readily, owing to diurnal fluctuations in temperature, while the junctions with the tillite are frequently hidden by sand and boulders. The general direction of glaciation is from the north-east, but there are two deviations which are sufficiently pronounced to invite comment. In the following table the bearings are in each case measured from the true meridian:—

| | |
|---|---|
| Ezel Klaauw Pan ... ... ... ... ... ... ... ... ... | S. 50° W. |
| Riverside ... ... ... ... ... ... ... ... ... ... ... ... | S. 55° E. |
| Omdraai's Vlei (west side) ... ... ... ... ... | S. 16° E. |
| Zoet Vlei and Welgevonden ... ... ... ... | S. 30° W. |
| Nooitgedacht ... ... ... ... ... ... ... ... ... ... | S. 28° W. |
| Roode Vloer (west side) ... ... ... ... ... ... | S. 20° W. |
| Middel Water—Holpan ... ... ... ... ... | S. 30° W. |
| Naauwe Kloof (north side) ... ... ... ... ... | S. 35° W. |
| Klein Modder Fontein (south) ... ... ... | S. 22° W. |
| ,, ,, ,, (north) ... ... ... | S. 45° W. |
| Jackals' Water (south-west) ... ... ... ... | S. 18° W. |

In the area to the north-east[1], while the general direction of glaciation is from north-east to south-west, over a large area in Hopetown and near Beer Vlei the ice-sheet seems to have been deflected in a direction east of south, possibly by reason of the obstruction caused by the ranges of the Doornberg. The striated surface on Omdraai's Vlei is evidently one that lies just within this area of south-south-easterly movement. The surface at Riverside is low down in what is now the valley of the Orange River, and the direction of striation is nearly parallel to this depression. Probably, therefore, the lower portion of the ice was deflected along the trough of the valley, and was thus caused to flow almost at right angles to the direction of movement in the main mass of ice.

[1] Ann. Rept. for 1907, p. 178.

The intensely hard varieties of Kheis quartz-schist make peculiar light-coloured hummocks rising from flats of tillite, on Klein Modder Fontein, Jonker Water, Naauwe Kloof, Middel Water, Groot Doorn Pan, etc., and have beautifully rounded and smooth surfaces. The finest surfaces, however, are those described some years ago from Jackals' Water.[2] Some of the more rugged ridges have not been ground down to quite the same extent, and may merely have their irregularities somewhat reduced. At Klein Modder Fontein, just below the homestead, on the edge of the pan, there are ledges of hard quartz-schist showing striated surfaces, which are sometimes vertical and occasionally undercut.

*Transport of Boulders.*—Many of the inclusions in the "boulder-beds" are of rocks which crop out to the north-east, thus confirming the evidence furnished by glacial striae.

There does not appear to be any invariable rule regarding the nature of the inclusions in different horizons of the tillite, but as far as can be judged boulders of local rocks seem more abundant at the base of the tillite than those of rocks which have been transported some distance. The contents of the boulder beds, however, vary considerably from point to point.

South-west of the Doornberg boulders of the banded jaspers of the Griqua Town series are fairly common, for example, at Welgevonden; the fragments of a shattered block, originally about eight feet across, rest on Kheis quartz schists close to the homestead on Klein Modder Fontein. At the pan on Groot Modder Fontein these jaspers are scarce, but boulders of the Campbell Rand limestone and the Pniel diabase are abundant. Travelling along the road from Omdraai's Vlei to Zoet Vlei, no inclusions of Griqua Town jaspers were seen until a point was reached just south-west of an outcrop of this rock on the right-hand side of the road, and here the tillite was full of inclusions. This is strong evidence for a south-westerly movement of the ice-sheet, as this exposure of the Griqua Town beds is the most southerly one in Prieska.

Again, no pebbles of the purplish Matsap grits were noticed when travelling westwards from Omdraai's Vlei until a point was reached a short distance north-north-east of Van Wyk's Vlei. This locality is situated south-south-west of the ridges of Matsap beds north of the Orange River. The Dwyka outlier on Ezels Klaauw at the extremity of the Ezel Rand is of interest on account of the large number of sub-angular blocks of Matsap quartzite and grit, often many feet across, in the tillite. In the Dwyka, boulders of Pniel diabase and amygdaloid generally predominate; inclusions of Campbell Rand limestone are fairly well represented, while in lesser numbers come granites, quartz-porphyries, Griqua Town jaspers, Kheis quartzites, Matsap quartzites, etc. Pebbles of a brilliant red

[2] Ann. Rep. for 1899.

jasper, such as is found both in the Kraaipan formation and in the Ongeluk series, are always to be found in the western part of Prieska, though they are never abundant and invariably small.

*The Boulder-beds.*—The Dwyka "boulder-beds" are never well seen except in ravines near the Orange River and artificial openings. Usually the matrix crumbles away, and the boulders, thus set free, cover the surface of the ground. This is especially well seen in the extreme west of Prieska and to the north of Van Wyk's Vlei, where the Dwyka forms a tract of undulating stony ground, rising considerably above the area to the south, and forming a portion of the Kaaien Bult.

This accumulation of boulders on the surface gives a false impression of the nature of the rock below, for the material, as seen in good exposures, contains only a comparatively small proportion of boulders.

The nature of the tillite in Prieska[1] was described in 1899, and there is little to add to this account. Generally, it shows no prominent bedding, but at Jonker Water there is a good deal of laminated rock, which at first sight would be taken for shale, but which contains numerous pebbles. On the west boundary of Prieska, at Bitter Puts, there is a ridge on which occurs a good deal of shaly material and limestone bands and concretions, but in which boulders are embedded.

The inclusions in the tillite are frequently of considerable size. At the north end of the pan on Klein Modder Fontein is a rounded boulder of Kheis quartz-schist 9 feet by 6 feet by 4 feet.

The hard variety known as gravel-dwyka, and composed of angular rock debris, cemented with calcareous and argillaceous matter, is abundant, usually in irregular more or less horizontal layers. Calcareous matter is common and sometimes forms lenticles and beds of gritty limestone, frequently with small inclusions. Limestone is abundant in the small outlier on Luis Draai, close to Ezel Rand.

The formation varies considerably in thickness, this being due partly to the uneven surface upon which the tillite rests.

A little to the west of Omdraai's Vlei, where only the crests of the underlying ridges of older rock are appearing as inliers, the tillite is reduced to an insignificant stratum. On Schilders Pan, close to the road south of the homestead, a little patch of gneissic granite is surrounded by shales from which a few pebbles have weathered out; there is no hard boulder bed here. On Nooitgedacht, at the nearer beacon north of the homestead, striated surfaces of granite are overlain by from one to two feet of hard calcareous tillite, and this in turn by shales and dolerite.

On Roode Vloer, about two and a half miles west of the large pan, the tillite—again a hard calcareous variety—is not

[1] Annual Report for 1899, and Trans. Phil. Soc. S.A. vol. xi. p. 113 and 6 plates.

more than three feet thick, followed by shales, flags, and limestone, the whole resting on an inclined surface of Kheis quartzite and granite, and dipping away from the latter at a considerable angle. This dip-away from the knobs of older rock is not uncommon, as, for example, a little more than a mile due north of the homestead on Holpan. On the road from Poortje down to Roode Vloer the shales above the tillite show dips up to 30°, altering in direction from point to point, the cause probably being the irregular surface of older rock which underlies the Dwyka hereabouts. In several places the tillite has a considerable thickness. At Jonker Water a borehole was put down in tillite to a depth of 114 feet, although mica schist crops out a short distance away. At Geelbosch Pan, in the midst of quartzite hills, is a small outlier of tillite in which a well has been sunk to a depth of 83 feet, and the floor of the tillite was not reached. On Vogelstruis Bult, Klipgat's Pan, and Kafir's Kolk is a "bult" rising to a considerable height and formed entirely of tillite. From the fact that shallow valleys in this high ground do not expose the older rocks, the "boulder beds" must be of considerable thickness. The same is probably true of the high ground to the north of Van Wyk's Vlei.

*The Upper Shales.*—The boulder-beds, when very thin, are followed abruptly by greenish or bluish shales, but wherever the former are well developed there is a gradual transition, the boulders becoming smaller and smaller.

West of Poortje it has been found possible to map an approximate boundary line between the tillite and the shale, as has been done in the south and west of the Colony. This boundary follows more or less closely the tract of low ground, or "laagte" as it may be termed, which extends from Klein Doorn Pan through Markt, Fourie's Kolk, Doorn Dam, Riet Brak, De Naauwte, and north-westwards down the Olifants Vlei River. The whole formation has a slight southerly dip, and the more rapid erosion of the shales has been the cause of the gentle depression separating the Karroo area in the south from the rising tillite-covered ground forming the southern end of the Kaaien Bult.

The shales are, as usual, dark-bluish in colour, with numerous calcareous and ferruginous concretions. Just below the "white-band" they may contain dark-greenish blue rocks, rich in carbonate of iron, which weather with brown, red, or purple surfaces, and finally become spongy, ochreous masses, for example, at Verkeerde Berg, near Van Wyk's Vlei.

At a number of points, but notably at the drift across the Ongers River below Houwater in Britstown, there are hard flaggy beds containing sandstone "concretions" showing remarkable false bedding and contorted lamination. This peculiar phase of deposition can be still better studied where the strata have suffered subsequent induration as, for

example, in a patch on the northern portion of Naauw Kloof in Prieska and on Klein Doorn Pan and Grenaat Kop. The laminae dip at high angles or may show extreme puckering and contortion in most irregular manner, whereas the stratum itself is lying nearly horizontally and quite undisturbed. Much light is thrown on the manner in which such beds may have been formed by a section of alluvium on the banks of the Orange River at Prieska. The spot is just where the small side stream from Prieska's Poort enters the Orange. The sand and clay, containing some vegetable matter, exhibited extraordinarily contorted bedding, the laminae being, as in the Dwyka specimen, frequently vertical or overturned.

It is evident that this curiously contorted lamination is produced where there is an eddy due to the water from the main stream rushing up the down-side bank of the ravine[1] though the process is not easy to explain.

*The White band.* This has the same lithological characters described in former Reports. In some places where the country is but slightly undulating these shales are hardly seen, but where the ground is broken the white shale becomes very prominent round the sides of dolerite-capped hills. The continuity of the strata is frequently interrupted by dolerite intrusions, generally slightly inclined sheets; but minor intrusions are especially abundant in the white-band itself. The junction between these uppermost beds of the Dwyka and the shales of the Ecca makes a sinuous outcrop across country from east to west, on the whole convex to the south. It strikes south-west from Strydenberg to Houwater, trending westwards through Jagt Scherm, Jackal's Pan, Roode Draai, Thomas (Ganna) Pan, Leeuw Kolk, to Van Wyks Vlei.

The unweathered carbonaceous pyritic shales were seen at a few points only, viz., on the railway a little south of Houwater, a well on Kommetjes Dam (Carnarvon), on Ganna Vloer below Verkeerde Berg and just below the Dam at Van Wyks Vlei.

## THE ECCA SERIES.

The Ecca beds form a belt trending nearly east and west, which is, roughly speaking, about 40 miles in breadth.

The Ecca-Beaufort boundary strikes south-westwards from Philipstown, crosses the Midland railway a few miles from De Aar and the Western railway at Mynfontein. It must then turn westwards, for the Beaufort beds appear in the high ground constituting the Stormberg on the boundary between Britstown and Victoria West divisions. Between this point and Pampoen Poort it makes bends round two projecting ridges and then turns north-westwards around the base of Beyer's Berg, striking for Carnarvon. The boundary, therefore, makes an irregular curve convex towards the south.

[1] Strong eddies at this point were seen in October, 1908, when the river was full and the section mentioned above under water

The series possesses the same argillaceous characters as in the area to the north-east.[1] The lowest shales are lighter in colour and of a more flaggy nature than those somewhat higher up; the latter are darker, more crumbly and contain numerous calcareous concretions. Approaching the base of the Beaufort series the shales again become more flaggy, and limestone nodules rarer. Cream-coloured sandstones are almost unrepresented. A few bands, each usually less than a foot in thickness appear in the ridges to the south-east of Britstown and again north of Uintjes Berg in Carnarvon, where they give rise to a terrace-like feature.

Dolerite sheets are abundant throughout this belt, and almost invariably form the high ground and the ridges. In between are extensive flats formed mostly of shale though not uncommonly the dolerite intrusions have weathered equally with the sedimentary rock. South-west of Van Wyks Vlei there are frequently no well-defined water-courses, the water after a rain spreads over the shale flats and covers them with a film of red mud. These red-clay flats are often miles in length and are called " vloers."

The thickness of the Ecca series is difficult to estimate, but judging from the uniform dip both of the underlying Dwyka and the overlying Beaufort series, checked by a deep bore-hole south of Van Wyks Vlei, it is probable that it cannot be less than 2,500 feet.

No fossils were obtained from these beds, though indistinct plant-markings are often abundant.

## THE BEAUFORT SERIES.

This formation is distinguished from the Ecca series by its typically arenaceous character. There are alternations of beds of pale yellow sandstone and bluish mudstone and shale, but the latter tend to weather more rapidly and their outcrops become hidden by blocks of fallen sandstone. The proportion of sandstone thus appears very much larger than is actually the case.

The scenery is typical of this formation; terraced and sometimes broken country crossed by dolerite intrusions. The latter are abundant, but more irregular in habit than in the Ecca. Moreover they form numerous narrow vertical dykes, a type of intrusion which is rare in the older formation. The passage from the Ecca into the Beaufort take place in a thickness of from 50 to 75 feet of alternating beds of hard blue shale and yellow sandstone, and this transition can be very well seen in some prominent outliers such as the Rhenoster Berg, Leeb's Kop, Matthews' Kop, the group adjoining Aasvogel Kop, etc.

---

[1] Annual Report Geological Commission for 1907, p. 182.

Each outlier consists of a pedestal of Ecca shales with one or more horizontal sheets of dolerite, surmounted by Beaufort sandstones and crowned with a sheet of dolerite, which may have a columnar structure.

Owing to the presence of the hard sandstones the slopes at the summit are always much steeper than in the dolerite-capped outliers of Ecca beds alone.

The base of the Beaufort beds in these outliers is very much higher than in the main area extending to the south; and this fact is of great value in indicating accurately the dip of the strata and in thus proving that the thickness of the formation must be much in excess of what would otherwise be suspected, for the low dips and the dolerite intrusions make any estimate difficult.

The formation has clearly been laid down in shallow water; some of the flaggy beds show good ripple-marking, while certain of the sandstones especially on Kalk Fontein, north of Victoria West, exhibit inclined and contorted bedding to a marked degree. A peculiarity of the sandstones is the frequent occurrence in them of large calcareous concretions oval or circular in outline and generally flattened. They are arranged along certain horizons, and being much harder than the matrix weather out in great numbers, acquiring a purplish brown tint externally. The bedding of the sandstone can often be traced through these concretions. They are usually from 3 to 6 feet across, and can be well seen at Victoria West between the town and the railway station.

The shales are pale-bluish or greenish in colour, often very arenaceous, and generally partaking of the nature of a mudstone. Purple shales first appear a short distance to the north of Victoria West, and may contain irregular nodules of hard impure limestone. The strata as a rule are deficient in calcareous matter and beds of limestone are hardly represented.

*Fossils* occur sparingly in the area that has been examined. Fragments of *Glossopteris* were obtained at Victoria West and on Riet Poort 20 miles to the north, and fish scales on Kalk Fontein, the adjoining farm.

A portion of a reptilian bone was picked up on the slopes of Tafel Kop (Rheebok's Fontein) not far from the base of the formation, while from Victoria West, in the kloof behind the town have come the following forms, described by Dr. Broom.[1]:—

*Arnognathus parvidens*,
*Heleosaurus scholtzi*,
*Galechirus scholtzi*,
*Heleophylus acutus*,
*Dicynodon*, sp.,
*Oudenodon*, sp.

[1] R. Broom. Trans. S.A. Phil. Soc., vol. xviii. p. 31, 1907.

This horizon is probably between 1,500 and 2,000 feet above the base of the Beaufort beds

*The Karroo Dolerites.*

Compared with their vast development in the Karroo strata the intrusions of dolerite in the older formations are quite insignificant and always in the form of narrow vertical dykes.

On Middel Ka, west of the Brakbosch Poort hills, there is a dyke of dolerite in the granite; it is a rather acid variety (2123) with a fair amount of micropegmatite, and the augite is not very abundant. Green hornblende is grown on to some of the augite, and there is some red biotite, ilmenite and apatite. The felspar is quite fresh and penetrates the augite.

Near Draghoender there are two dolerite dykes in the granite; one has a W. 20° N. course, and the other runs N. 20° E. A slice from the latter (2054) shows that it is a usual type of dolerite with very little olivine.

In the Dwyka and Ecca series the intrusions are almost solely in the form of horizontal or inclined sheets, vertical dykes being rare; in the Beaufort series, however, the latter type of intrusion is very common.

In the whole of northern Cape Colony vertical dykes seem to be prevalent in formations composed of hard rocks, whether massive or bedded, whereas sheets predominate in formations that are essentially shaly.

Sheets are rarely found in the Dwyka tillite, and then only near its upper limit, as, for instance, in the large outlier on Groot and Klein Fourie's Kolk. The most important and extensive intrusion of this type is found in the Upper Dwyka shales almost continuously from the east side of Hopetown as far as Van Wyk's Vlei without dying out. A low irregular and much indented escarpment is thereby produced; below the capping of dolerite are usually seen the shales of the " white-band."

Throughout this area, too, there is the same tendency in the behaviour of the sheets as has been noticed in the Tanqua (Calvinia) Karroo, they pass from lower to higher horizons as they are followed from north to south. Confirmation of this is found in the deep borehole at De Aar, which met with very little dolerite at great depths.

The inclined sheets of dolerite have a tendency to run across country from east to west, and usually have a southerly dip. They thus form lines of rugged hills having slopes of dolerite on one side and on the other an escarpment, below the crest of which shales appear. Such intrusions are well seen in the neighbourhood of Vosburg. The trend of these sills not uncommonly changes, forming curved outcrops so that peculiar closed chains of dolerite ridges, similar to those which are so

prominent a feature in Queenstown and Glen Grey, have been produced. One of these ring-shaped intrusions is found at De Aar enclosing the farms Sinclair's Dam, Klein Brand Fontein and Zwart Kopjes (north). It is about 8 miles across; the dolerite forming the ring dips inwards at an angle varying form 20° to 60°, and in the south the sheet rises and caps the high ground on Zwart Kopjes (south) and Smous Poort.

A second example of one of these basin-shaped areas, of about the same size, contains the farm Ercildoune, near Britstown, and is of interest because the centre of the depression is occupied by a pan. A smaller but fine example occurs at Elands Fontein in the south-west of Britstown. In the south the dolerite rises to cap the hills on the boundary of Victoria West, while outliers remain on Matthews' Kop and Leeb's Kop. The shales in the interior of the basin only cover a small area.

Another large intrusion of this type penetrates the Beaufort beds a little further south on Hex Rivier, Duivel's Nek and Kalk Fontein. In contrast to these large rings there is the miniature ring at Vosburg, just outside the village on its north side. It is about one and a quarter miles long and three-quarters of a mile broad, and the dolerite sheets dip in at a low angle on all sides.

Horizontal sheets one above the other are to be found in the higher ridges especially where the Beaufort beds are still present, for example, Leeb's Kop, the hills around Aasvogel Kop, Beyer's Berg, Pretorius' Kop, etc. A peculiarity of the lower sheets is the habit they have of crumbling away so that in many places the outcrops of such intrusions on the slopes are scarcely noticeable. The uppermost dolerite invariably makes a marked feature, and frequently the rock is rudely columnar, as on Aasvogel Kop. In Beyer's Berg the columns are slender but extremely well developed, and the summits of the mountain are formed of jagged dolerite pinnacles, the slopes of which are strewn with prism-shaped fragments.

The irregular weathering of the dolerite gives rise to a peculiar type of landscape where the sheets cover the less elevated portion of the country. Through differential weathering knobs and pyramids of jointed dolerite are found scattered over the country, while in between them the rock has crumbled to a coarse yellow-brown sand. The best locality where this type of weathering can be observed is on the farm Upper Zwart Rand in Carnarvon, but there are many other localities near Pampoen Poort and Kweekwa. This habit of the dolerite of breaking down to a sandy material is very prevalent throughout this area wherever the surface of the ground is flat or but gently undulating; in numerous cases it is only possible to distinguish the area of igneous rock from

that occupied by shales by the differences in character of the soils or from the fragments of rock brought up in animal burrows. A specially troublesome piece of country is found just north-west of Vosburg, where there is a good deal of sand and tufa.

There can be no doubt that the chemical weathering is more rapid in places where the dolerite forms flat ground than where it builds ridges. The degree of weathering seems also to be affected by the composition of the rock to a considerable extent.

This dependence on composition is well illustrated in an intrusion at Leeuw Kop, south-east of Vosberg. The dolerite forms a dyke-like mass trending east and west, and a thin section (2017) under the microscope proves it to be an ophitic olivine dolerite. The felspars are small in comparison with the augites in which they are enclosed; there is very little biotite or quartz.

Both to north and south lies a rotten crumbly sheet of coarse dolerite resting on shales, and a section (2018) from an unweathered kernel shows much larger felspars, while the structure is no longer ophitic. Olivine is still present, but in lesser quantity; biotite is more abundant, while spaces between the felspar are filled with a micrographic intergrowth of quartz and clouded felspar, probably orthoclase. Further to the east the sheet can be seen to merge into the dyke, the rock possessing characters intermediate between the types just described; but at the Leeuw Kop itself it seems as if the dyke were intrusive through the sheet.

It is only to be expected that in such an extensive group of intrusions some varieties should differ slightly in age and composition from others. In the ring-shaped intrusion at De Aar, at several points the coarse dolerite is irregularly veined with a fine-grained darker and less altered variety, as if a second intrusion had penetrated and mingled with the first just before the latter had solidified. A more acid intrusion at De Poort has followed approximately the junction of this dolerite with the shales, and the latter are highly metamorphosed while the intrusion itself shows a streaky and spotted character, and is often difficult to distinguish from the sedimentary rock. A section (1931) of this intrusion proves it to be a dolerite with granophyric structure. The felspars are clouded and surrounded by large areas of micropegmatite; the augite is pale in colour and sometimes altered to diallage; in places it is intergrown with a brownish hornblende, but some pale hornblende appears to have been derived from the pyroxene. The accessory minerals are ilmenite in large plates, apatite, and sphene. On the road from De Aar to Zwart Kopjes there is a dyke about 8 feet wide of fine-grained dolerite cutting through this ring-shaped intrusion. The dyke

shows chilled edges. At Brand Fontein, just as at Leeuw Kop, there is a sheet of rotten crumbly dolerite at the foot of the dolerite ridge. A fresh portion of this rock (1932) is found to contain largish areas of felspar, showing albite twinning, interlocking with quartz and pale brownish augite. The latter is sometimes altered to diallage, and is intergrown with enstatite now changed to bastite or serpentine.

On Kalk Fontein, north of Victoria West, there is a dolerite dyke cutting vertically through a horizontal sheet of dolerite. The latter (2020) is an ophitic-olivine dolerite with rather large felspars, and it contains a very little micropegmatite. The former (2021) has the same mineral composition, but the felspar is in lath-shaped areas while the augite forms little granules.

On decomposition a portion of the lime present in the minerals of the dolerite is set free, and combining with carbonic acid forms carbonate of lime. Much of the calcareous tufa on the Karroo flats, especially that covering decomposed dolerite has been formed in this way, still a considerable portion of the tufa must come from calcareous matter in the shales. There is a very interesting hill known as Spitz Kop on the farm Vogelstruis Fontein, north-east of Britstown. It is formed of a great mass of jointed dolerite on a pedestal of shales. High up, almost at the summit, is a large amount of limestone cementing the blocks of dolerite and showing that the calcareous matter must have been derived from the igneous rock itself.

On the farm Middel Water, on the Brak River in Britstown, there are four peculiar pipe-like occurrences arranged in two groups about a mile and a quarter apart. In each case the material in them is highly decomposed and forms a yellowish calcareous soil full of animal burrows, and only here and there are there fresh portions of the less altered rock. The surrounding shales are disturbed and usually tilted away from the contact. The two south-eastern occurrences are very small; the third one is about 250 feet across and contains a fine-grained altered porphyritic variety of dolerite, in which the original micas have been altered to chlorite.

The fourth pipe is about 200 feet across, and consists of masses of light-coloured acid dolerite, which in thin section (1937) shows beautiful micrographic intergrowths of quartz and felspar in which are set rectangular orthoclase felspars and a little green hornblende altering in places to chlorite.

In habit these pipes recall those filled with kimberlite, but the rocks in them certainly belong to the Karroo dolerites, and no fragments of peridotite or granulite were found, nor were any of the characteristic minerals of the "blue-ground" observed.

## Superficial Deposits.

The superficial deposits in this area are chiefly sand and surface limestone. Along the Orange River there are small patches of gravel and strips of alluvium, but they do not extend far from the banks.

The alluvial deposits are fine-grained and grey or yellowish in colour, banded with dark laminae containing more vegetable matter than the rest of the material. At the mouth of the Prieska ravine a certain bed of alluvium on the left bank has its laminae contorted. They often stand vertically, and are even curved in the shape of an inverted bulb. Above and below this layer the laminae are false-bedded or lie flat. Further up the ravine the material is less disturbed.

The difference between the gravels of the Orange River and those brought down by the local stream from the Doornberg in this locality are sharply distinguishable by the nature of the pebbles; the Orange River gravels contain numerous fragments of the Drakensberg lavas.

In the Koegas ravine there are nearly continuous sections of the alluvium for some 800 yards above the mouth. The greatest thickness exposed is about 20 feet. The laminae lie flat in the greater part of the sections, but near the mouth of the ravine they are strongly false-bedded in layers 1½ to 2 feet thick, separated by pronounced horizontal partings. On the left bank of the ravine (up-stream side of the mouth as regards the Orange) the inclination of the laminae in the false-bedded layers is up-stream as regards the ravine; on the right bank of the ravine it is down-stream.

In the higher parts of the ravine there are a few layers of red sand up to 8 inches thick interbedded with the drab-coloured alluvium. They look like the red sand from the interior of Griqualand West and the Kalahari.

The surface limestones are widely distributed, though they do not reach the importance of similar rocks in Griqualand West. Only occasionally, on the Dwyka and granitic area west of the Doornberg and on the Kaaien Bult, are they thick enough to cause doubt as to what lies below; but in those localities they tend to obscure the boundaries of the Dwyka formation.

On Nauga and Koegas some patches of gravel are cemented by limestone.

On the west side of the Doornbergen, on the farms Geelbeck's Dam and Kameel Boom, there are some well-marked gravel fans heading towards kloofs in the hills, but they are now cut through by stream beds and to a great extent separated from the hills by lateral ravines, so they are in process of destruction. These old fans extend some two miles from the

hills, and their thickness may be as much as 50 feet. The size of the fragments, which are subangular in shape, decreases with some regularity from the middle and highest part outwards. Rather similar accumulations of subangular gravel are now being formed at lower levels. Limestone is occasionally seen cementing the fragments in both the old and newer fans.

Sandy soils are usually found on fairly flat ground underlain by the pre-Karroo rocks. Towards the Orange River the sand becomes more abundant, and in the valleys surrounded by the Kheis beds of the Keuk-en-Draai-Brakbosch Poort hills it hides the underlying rock almost completely. In 1899 there was no evidence seen of the presence of the Dwyka at Geelbosch Pan, though now wells prove that over 80 feet of it exist there. It is possible that the sand hides similar outliers elsewhere.

There is a very interesting narrow belt of sand dunes along the Olifants Vlei River near Van Wyk's Vlei. According to the military map this belt commences on Bril Zijn Dam and strikes eastwards to Breek Kerrie. Here it unites with a strip which stretches to the east-south-east, broken at one point where advantage has been taken in making the road from Van Wyk's Vlei to Kenhardt. At Nieuwe Dam the belt of parallel dunes is only 600 yards broad, but it widens to the south-east partly burying the dolerite ridges on Verkeerde Vlei. The Verkeerde Vlei Pan breaks the continuity of the dunes, but on its opposite side the sand forms a belt of extremely heavy country about 4 miles in width, covering up shales and dolerite on Leeuw Kolk, Ganna Pan, and Sand Pan. Smaller strips of sand occur at Zaai Laagte and Elands Been. Another important stretch of sandy country is found below the dolerite escarpment and extends almost continuously from Klein Markt through Buffel Bout to Poortje and Wiel Pan. At Buffel Bout the dunes lie nearly east and west and make travelling very heavy. The red sand is mostly fixed by long grass, and these strips of sand veld form excellent grazing country. From information given by the residents the dunes appear to be moving towards the south-east, but at an extremely slow rate.

Very curious are the patches of bright red sand which are found here and there on the leeward edges of the dolerite ridges on Klein Markt and Springbok Poortje. Although they exist on the summits of the ridges in the form of small dunes, yet it is remarkable to find that the sand is not travelling down the hill sides under the action of the prevailing north-westerly winds. Several of the farmers in the neighbourhood state that these patches of sand have not changed their positions during the last thirty years. The explanation is that the wind sweeps the grains of sand over the edge of

the ridge but the eddy produced on the slope returns the sand to its former position.

Round the Buchu Berg and Ezel Rand the sand is most abundant on the north-west side of the hills, and it creeps far up the slopes on that side.

In the northern part of the area sand-dunes are not frequent, but a remarkably long and straight one runs W. 25° N. from Blink Fontein to Blaauw Puts.

The colour of the sand is reddish, and it resembles closely the sand of the southern Kalahari and the neighbouring parts of Kuruman and Hay.

# THE KIMBERLITE AND ALLIED PIPES AND FISSURES IN PRIESKA, BRITSTOWN, VICTORIA WEST AND CARNARVON.

By Alex. L. du Toit.

Pipes and dykes filled with kimberlite (blue-ground) or some allied material, are extremely abundant in this area, and although in every case the diamond has proved either to be absent or to exist only in very small quantity, yet the presence of these dykes is of considerable importance economically in connection with water-supply. Abundant important geological information has been obtained concerning the granulites and eclogite inclusions in the blue-ground, while the determination of ultrabasic lamprophyres forming dykes is of importance in connection with the question of the genesis and affinities of kimberlite itself.

In what follows brief reference will be made to the characters and modes of occurrence of some of the pipes and fissures. while the petrological descriptions of their contents will be dealt with in a separate section,

## I. Pipes.

On Du Plessis Dam, a few miles to the north-east of De Aar, there occurs a small pipe amid shales. The occurrence has not been opened up, but the surface of the ground is strewn with small fragments of garnetiferous granulites, some of which are of interest in containing the mineral cyanite. Dolerite, shales and gneiss are also represented. A narrow dyke extends for at least a mile in a southerly direction from this pipe towards Badenhorst Dam.

On Vet Laagte, close at hand, a pipe was opened up some time ago and shows hard green kimberlite rich in ilmenite. No granulites are represented, only some ultra-basic rocks, while garnet is absent from the wash or else must be extremely rare.

Between Sweet Put and Zout Put, north of Britstown, there is a pipe which is situated on the edge of a pan. Its exact boundary has not yet been determined and it may extend some distance into the pan, while some kimberlite exposed in an opening one hundred yards to the south may possibly be a portion of the same mass. From the pipe a fissure filled with hard micaceous kimberlite, and from four to five feet wide, extends for a distance of several hundred yards in an easterly direction cutting through shale and dolerite. The pipe has been prospected and diamonds are stated to have been obtained in the yellow ground.

Among the inclusions are granitic rocks, including graphic granite, but there is a long series of more basic varieties ending in gabbro; the granites are usually much decomposed. No garnetiferous rocks are represented, but there are large numbers of lumps of a hard grey rock which is probably an altered lamprophyre, and which contains a fair amount of pyrites. On Blaauwbosch Put, east of Britstown, close to the railway, a large area of kimberlite has been opened up containing a varied assortment of garnetiferous granulites.

In Britstown, on the west side of the town, pits have proved the existence of kimberlite, but the habit of the occurrence is not known. Among the inclusions were a fragment of eclogite and one of hornblende-schist.

Further west is a pipe about 150 yards in diameter on the boundary between De Kraalen and Paarde Vallei, close to the Ongers River; the northern limit is defined by a semicircle of dolerite. Many fragments of garnetiferous granulites, and also some biotite-granite and hornblende-schist were found in the material thrown up out of prospecting pits. At the extreme western end of the farm Middel Water (southern farm of that name) in Prieska there is a very interesting little pipe, probably not more than 20 yards across. The walls are formed of hardened shales, flags and limestones belonging to the Dwyka series, tilted and very much broken. Both the rocks forming the walls and fragments of the same found within the pipe show faulting, often on an extensive though minute scale. Round about are exposures of Dwyka tillite, while within a couple of hundred yards are hummocks of Kheis quartzites and the accompanying intrusive granite. In the central depression marking the pipe are found angular fragments of Kheis quartzite and mica-schist, granite and amphibolitic rocks, together with well-rounded lumps of granite and various granulites.

On Kalk Put, near Vosburg, an elongated pipe has been opened up and contains boulders of gneiss, pegmatite and amphibolite. Some brecciated shale has been baked into an intensely hard material, evidently by the action of the kimberlite when in a heated condition.

On Cordaat's Kuil (Victoria West) there are two pipes, the more important of which is located close to the eastern boundary of the farm. It penetrates a sheet of dolerite, and its western limit is well defined; on the east the soil is thicker, but it seems very likely that the pipe extends in this direction, in which case it would be from 250 to 300 yards in length and about 100 yards across. A number of shafts prove pale bluish kimberlite quite close to the surface. Diamonds are said to have been found in the deposit; garnet and ilmenite seem to be scarce.

The area occupied by the pipe is strewn with inclusions, prin-

cipally of dolerite, but granulites are well represented along with syenite-gneiss and some decomposed basic and ultrabasic rocks.

Further to the north, on Human's Dam—called on the Divisional Map " Adjoining Vogelstruis Fontein "—some prospecting pits have proved a body of kimberlite at the foot of a ridge of dolerite. Inclusions of dolerite are numerous, while fragments of biotite-gneiss and amphibolite are common.

About 600 yards further to the north, on Brandewyn's Kuil, there is a pipe surrounded by a ring of dolerite and remarkably clearly defined. It is oval in outline, about 300 yards in length, and the breccia filling it has weathered into a highly calcareous material forming a gently convex surface. Pale blue-ground is found a few feet below the surface in some of the pits. There are several large masses of " floating reef," principally shattered blocks of shale; in several spots the latter are much brecciated, considerably hardened, and zeolites have formed in the joints and cavities. The inclusions are like those in the pipe on Human's Dam, but there is in addition a curious gneiss-breccia firmly cemented with a material allied to kimberlite.

On Wit Puts, a portion of Roode Draai, there is a pipe about 120 yards in diameter.

A narrow elongated pipe occurs about two and a half miles south-east of the homestead on Markt (Prieska); the boundaries are not well defined. Inclusions of dolerite and Dwyka shale and tillite are abundant, and there are also gneissic-granite, hornblende-schist, garnet-gneiss, garnet-granulite. An inclusion of eclogite formed a perfectly smooth boulder, oval in outline with a longer diameter of about 15 inches. There are numerous fragments of dark-greyish igneous rock, often vesicular, like those found in the Uintjes Berg pipe.

This latter occurs at the base of Uintjes Berg, a little more than a mile north of the homestead. It is about 200 yards long and from 60 to 80 yards across, the breccia forming a hummock surrounded by Ecca shales. There is considerable variation in the nature of the contents at different points in the pipe. Generally speaking fragments of shale are so abundant at the periphery that in places the kimberlite matrix can hardly be distinguished. At the northern end of the pipe fragments of kaolinised granite or biotite gneiss are numerous, along with gneissose granites (occasionally garnetiferous), apparently different from any rocks found in Prieska. In the middle portion garnet-granulites occur; while in the south there is an abundance of large inclusions of compact and amygdaloidal basaltic rocks. In the centre of the pipe is an elongated area of hardened brecciated shale, sometimes broken up into extremely small particles cemented together, the induration having seemingly been accomplished by a narrow body

of intensely hard kimberlite, which projects above the surface of the ground and weathers with a rough-pitted exterior. Close to the homestead is another pipe, also elongated, in a north-north-easterly direction. The material exposed in pits is again a jumble of fragments of dolerite and shale with a small amount of groundmass. Kimberlite dykes are abundant round about on this farm.

On Grenaat Kop, and Klein and Groot Doorn Pan, there is a peculiar type of alteration in the Dwyka series which can be connected with the existence of pipes and fissures, and which recalls the phenomena around Saltpetre Kop in Sutherland.[1]

On the north side of Grenaat Kop there rise from a flat of Dwyka tillite three little hills, the highest of which is known as Los Kopje. (See Fig. 1.) The central elevation is a vol-

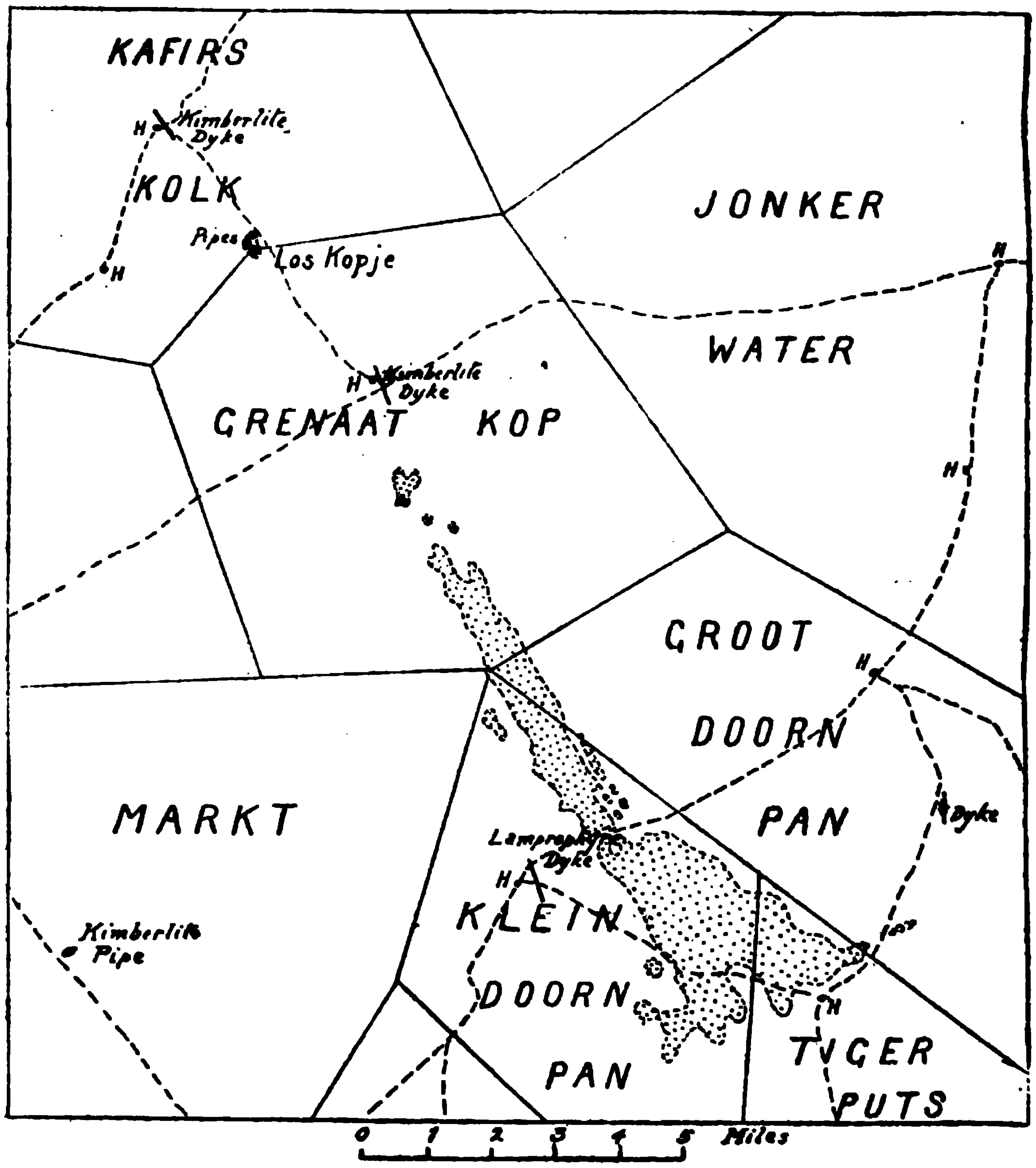



FIG. 1.—Map showing the area over which the Dwyka has been altered.

[1] Annual Report for 1903, pp. 57–67.

canic neck about 200 feet long and 100 feet broad, and is formed of an intensely hard breccia composed chiefly of fragments of indurated shale and flagstone, commonly without any matrix, sometimes cemented together by a yellowish-brown material. The wall of the pipe is exposed on the east side, the Dwyka shales and limestones being brecciated and hardened and dipping inwards.

The breccia contains a number of masses of a much altered brown rock, probably a variety of kimberlite, rounded to sub-angular, and up to one foot across. In a thin section (2273) of this rock the only minerals that have escaped alteration are a pale yellow and very fresh idiomorphic mica and abundant minute crystals of perofskite. The rest of the rock consists principally of calcite with a little serpentine, and is clouded by yellow-brown limonitic material. Olivine was certainly originally present, probably also a pyroxene.

The northernmost kopje is also a small vent which is filled mostly with a gritty breccia containing numerous boulders from the Dwyka as well as deep-seated rocks, such as amphibolite, and also some Karroo dolerite; a small mass of shale-breccia occupies one side of the pipe. Northwards there runs a line of fracture along which the shales and tillite have been markedly indurated.

The Los Kopje itself probably marks a vent also. The breccia forming the hill is composed principally of shale and limestone fragments, and contains a few boulders of gneiss. The vent is situated on a line of fracture on either side of which the sediments have been hardened.

The Grenaat Kop itself is formed of these indurated Dwyka shales, while a broad belt of similar beds extends in a south-easterly direction to Tiger Puts. It seems most likely that, as around Saltpetre Kop, the induration of the sediments has been caused by heated waters charged with mineral matter ascending along cracks in the strata. At numerous points, notably on Grenaat Kop itself, and on the ridge immediately to the south-east of it, these channels along which the solutions rose can be traced out. In the shales the fracture is marked by an irregular narrow band of brecciated rock commonly only a few inches wide. On either side the shales are very much hardened, usually for a distance of from 4 to 6 feet, beyond this the rock shades off into unaltered shale. These lines of induration make dyke-like outcrops in the area of soft shales. Where a sandy and presumably more porous layer is cut, the solutions seem to have been able to spread out laterally much further from the line of fracture, and such layers have been converted into rocks resembling cherts or fine-grained quartzites. The flagstones and the shales have thus been unequally affected. In the altered rocks the bedding planes are usually distinct, but vertical jointing is so well developed that the material tends

to split much more readily along these joint planes. The shales have become hard and splintery, and are usually cream or buff-coloured, and are stained here and there irregularly to a brown or deep purple red colour. The sandstones are more commonly pale grey or yellowish in tint. The limestone concretions in the shales have in places acquired a semicrystalline structure.

A section (2247) of a fine-grained rock, once a sandstone, shows that the original minute grains of quartz and felspar have been enlarged by secondary growth and their boundaries rendered indistinct. Tufts of sericitic mica are abundant; while ragged patches of limonite give to the rock its pinkish colour.

On the east side of the belt, just north of the road from Klein to Groot Doorn Pan, the induration of the Dwyka boulder bed can be well studied.

At the extreme southern end of the belt is a patch of highly altered vesicular igneous rock probably marking a volcanic neck; possibly, however, it is more of the nature of an intrusive sheet.

Some distance to the south-east of the homestead on Groot Doorn Pan a little patch of these indurated beds, not more than 20 yards across, is found. Across it cuts a dyke of some highly decomposed material, probably allied to kimberlite, for in it were found boulders of garnetiferous granulites.

The induration of the sediments can be explained on no other theory than that advanced. It is true that small intrusive sheets of dolerite are found close at hand, but the type of metamorphism which they produce is entirely different. The hardening and staining of the rocks could only have been accomplished by solutions, and the occurrence of dykes of kimberlite and lamprophyre at the homesteads of Kafirs Kolk, Grenaat Kop and Klein Doorn Pan show that the metamorphism was intimately connected with the kimberlite, for it is noteworthy that they all occur along a certain zone striking nearly north-west. The whole appearance is remarkably like that around Saltpetre Kop, and is strong confirmation of the view that all these various occurrences are merely different phases of a single type of volcanic activity.

## II. Dykes and Fissures.

Dykes of kimberlite, and not uncommonly of lamprophyre also, are so numerous in the area under consideration that it is only possible to give a general acount of their mode of occurrence with more detail in the case of several unusual types.

These dykes are generally located by the lines of bush or "aars" to which they give rise on the surface, by the peculiar

yellowish calcareous soil thrown out of the animal burrows situated on them, and by the presence of boulders of granulites and fragments of mica, ilmenite and garnet along the outcrop. Often, too, the shales on either side of the dyke are tilted up at high angles for a distance of several feet or yards even. (See figs. 2 and 3.) This feature is characteristic of these dykes, but is not confined to them, for on Ganna Pan (Thomas Pan), in Carnarvon, the strata have been tilted almost vertically alongside a dyke of decomposed Karroo dolerite.

The economic importance of these dykes is very considerable in connection with water-supply. Wells or boreholes sunk on them rarely fail to yield supplies superior in quantity and quality than can be obtained either in the sediments themselves or in dolerite dykes intersecting them. Moreover, as has been

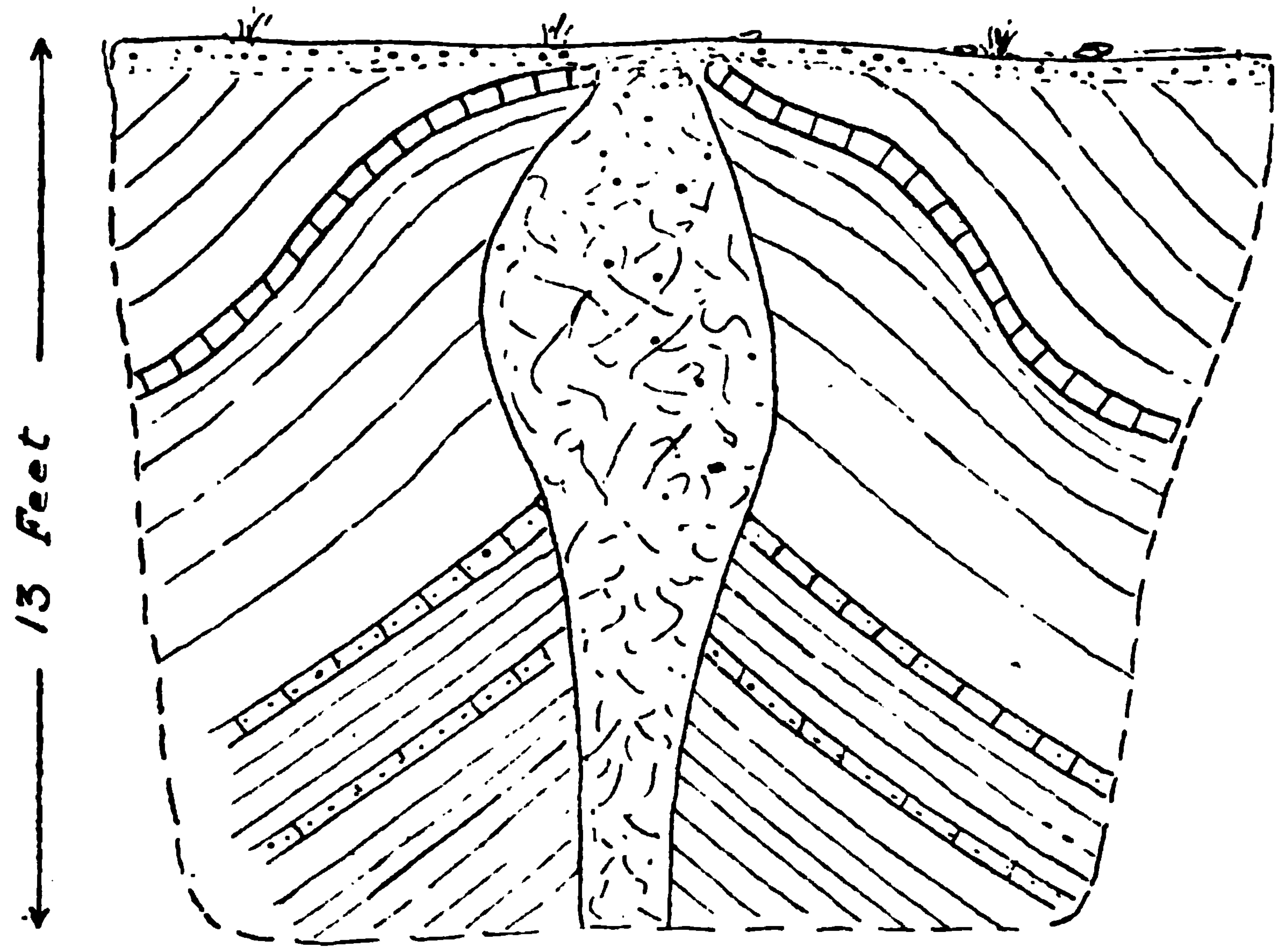



FIG. 2.—Shales and sandstones tilted by Kimberlite dyke, as seen in a well-cutting, Slypsteen, Omdraai's Vlei.

pointed out, such dolerite dykes are rare in the Ecca beds, while in the Beaufort beds again the supplies of water are always weak owing to the fine-grained compact nature of the predominating sandstones. In these kimberlite dykes the rock is decomposed to considerable depths as a rule, wells are easy to sink, and water is usually got at a shallow depth.

As an example, the farm Elands Been, in the south-western corner of Prieska, may be cited. There are about half a dozen kimberlite dykes on it, three of which intersect at a point where a well has been sunk.

In a number of instances the strike of these dykes is obviously connected with the direction of the joint or other planes in the

harder rocks underlying the Karroo formation, a peculiarity that has already received comment.[1] Thus two miles west of Omdraai's Vlei a dyke has a north-westerly strike parallel to, if not perhaps situated upon, the Doornberg fault. At Zoet Vlei another is found with strike coinciding with the direction of cleavage in the adjoining Marydale volcanics. The north-westerly strike of the belt of altered sediments and the dykes on Grenaat Kop, etc., has already been referred to, and the same is the case on Plat Sjambok, Uitzigt, and Springbok Poortje, such being parallel to the direction of the Kheis rocks and the belts of granite, but on Middel Water (west) and Klein Modder Fontein the kimberlite dykes have a north-easterly trend instead.

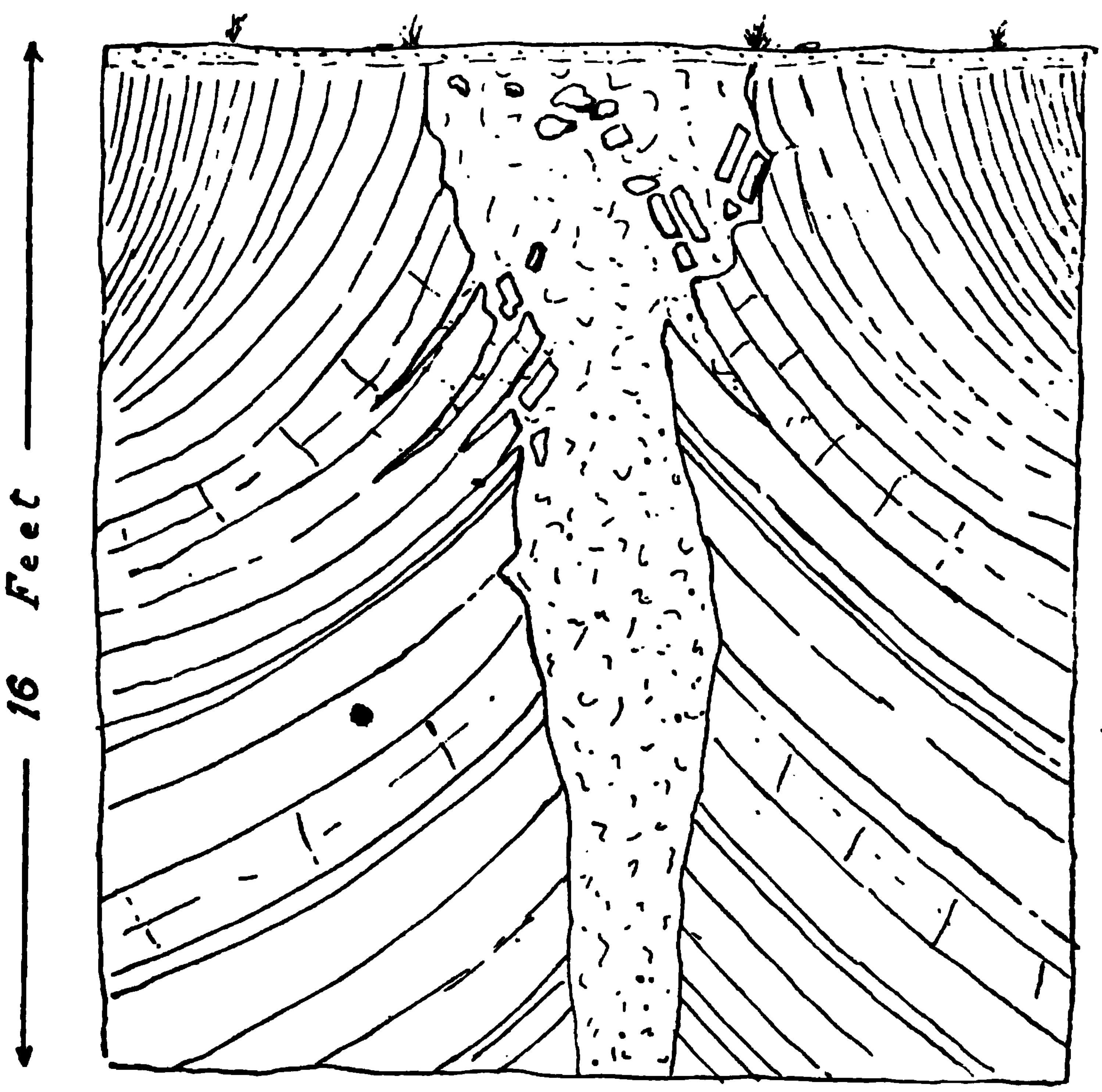



FIG. 3.—Shales tilted by Kimberlite dyke, as seen in a well-cutting, Elands Been, Prieska.

The material forming these dykes is usually a yellowish or greenish rock, very much decomposed but commonly rich in small plates of mica, and this leads one to suspect that perhaps these intrusions are more closely allied to the group of rocks classed as lamprophyres than to the material called kimberlite.

[1] Annual Report for 1906, p. 148.

It is, therefore, of great interest to find that certain of these dykes actually do belong to the group of the lamprophyres.

(1961). *Monchiquite*, a narrow dyke crossing boundary between Riet Gat and Holpan, west of Houwater, Britstown. The thin section shows greenish yellow areas of serpentine after olivine, and upon which the mica is sometimes moulded. The latter is usually in pale yellow brown idiomorphic crystals, often with a darker border of the abnormal variety, and is uniaxial. It contains finely divided dusty matter in places. Augite builds up prisms, and in places exceeds the mica in size; it has a very faint greenish tinge. There is an abundant groundmass, colourless but crowded with dusty material, rods of augite, fibres of serpentine, etc. It is isotropic, and stains after treatment with acid. It is, therefore, analcime. There is a little calcite and some granules of sphene.

This rock can, therefore, be termed *monchiquite* a variety of lamprophyre characterised by the presence of a groundmass of analcime.

(1962.) *Lamprophyre*. Two miles west of Omdraai's Vlei station. The rock contains large porphyritic olivines replaced principally by calcite and quartz crammed with minute rutiles and secondary micas. The beautifully idiomorphic pale yellow mica is usually surrounded by a shell of the abnormal variety. The second generation consists of small micas mostly abnormal in character. The rock exhibits a fine fluxion structure, rows of micas curving round the olivine pseudomorphs. Augite is fairly abundant, but being in small prisms is apt to be overlooked at first. The groundmass consists of large crystal areas of calcite along with some mineral, probably a zeolite; these are probably derived from the alteration of the original base. Of the numerous dark granules some are perofskite; some of the other patches are of iron ore, some being large.

This lamprophyre seems to be very closely allied to the alnöites (" melilite-basalts ")

(2218.) *Lamprophyre*. Dyke from 1 to 4 feet wide on Riverside, north-west of Prieska. Yellow-green rock; olivines completely altered. Pale yellow mica forming the bulk of the rock; much broken up by serpentine and calcite interposed along the cleavages. Minute perofskites and a few grains of iron ore.

(2220.) *Lamprophyre*. Narrow dyke on northern boundary of Prieska Commonage, traceable for about 1,000 yards, and widening to 12 feet in the south. It gives off thin veins into the Dwyka, and the limestone inclusions in the tillite close to the dyke have been rendered crystalline.

Olivine, sometimes with idiomorphic outlines, completely altered. Numerous prisms of colourless augite of small size, in places altering on edges into a pleochroic green hornblende, possibly derived from aegerine-augite. The biotite is reddish yellow-brown in colour, rather streaky in appearance and is normal. It is moulded on the olivine and pyroxene. There is a very little much altered felspar and a few grains of iron ore. The groundmass seems to be rather dusty serpentine.

(2221.) *Lamprophyre*. Same dyke. Olivine as before. Mica abundant; normal but shows stronger pleochroism in basal flakes than in other sections; yellow to brown red, biaxial. Prisms of colourless augite terminated by a green mineral which in part is certainly aegerine. Usually, however, this mineral has the pleochroism of acmite with a lower double refraction, and with extinction angles as large as those of augite.

The groundmass consists of colourless untwinned felspar full of cloudy matter, and greenish fibrous stuff; in places it has been much altered. Some iron ores are present.

The rock recalls a specimen (1561) from Llanover,[1] and is probably closely allied to the camptonites.

(2222.) *Lamprophyre*. A vein about threequarters of an inch wide in the Dwyka tillite at the same locality. Olivine is absent, and the rock is evidently less basic than the previous specimens. Idiomorphic biotite is abundant; it has dark borders and is sometimes attached to and moulded on the augite. The latter is present in quantity in long colourless prisms bordered by, and more especially terminating in, green aegerine into which the augite passes insensibly. The smallest prisms are greenish, and some of them consist solely of aegerine. Sometimes they form radiating bundles, and then the tint may be brown as in acmite. The groundmass consists principally of felspar, generally forming roughly polygonal areas dusty in the interior, this being due mainly to finely divided calcite, mica and iron ore. No twinning can be made out, but from the presence of calcite as a decomposition product the felspar may be perhaps oligoclase, passing outwards into orthoclase. Calcite forms large areas in which are set crystals of felspar, mica, augite, etc., as if it had replaced a glassy base. There are a few granules of sphene.

Close to the homestead on Klein Doorn Pan is a dyke of lamprophyric rock showing some interesting features. The rock thrown out of a well is somewhat friable, and in it are set rounded boulders up to 10 inches across, of a peculiar altered

[1] Annual Report for 1906, p. 159.

granite rock with some fragments of dolerite. These inclusions are in places so numerous that the rock resembles a conglomerate. At the contacts with the boulders the intrusive rock is sometimes very micaceous, the mica flakes tending to form a shell around the inclusion. The occurrence is of interest in forming a link between the purely intrusive dykes and those in which the eruptive material has been brecciated and become mingled with foreign material. A section (2245) shows olivine altered to dark green serpentine. Abundant micas ranging in colour from pale yellow to blood red, the darker variety being confined to the borders of the crystals and being as a rule an abnormal variety. The mica frequently encloses the olivine pseudomorphs; in places it is split up by secondary minerals. Augite is present in colourless prisms, the smaller ones forming aggregates. Iron ores and granules of sphene are present in quantity. Calcite forms little patches between the other minerals.

A vein about two and a half inches wide, cutting through dolerite, shows the following characters in thin section (2244) under the microscope. Porphyritic olivines are altered to serpentine, the latter nearly colourless in the interior, and yellow-brown, fibrous, with strong double refraction along the periphery. The mica forms the bulk of the remainder of the rock, and the crystals are arranged in places tangentially round the olivines. There are two generations, and the mineral is pale yellow with frequent darker borders of an occasionally optically abnormal variety. Augite in prisms was probably originally present, but is now pseudomorphed by calcite. The groundmass is principally calcite with some serpentinous matter. Abundant granules of iron ores and a very little perofskite.

On the farm Brak Kuilen, north-east of Britstown, there is a well sunk probably on a kimberlite pipe, and from it a large fragment of a lamprophyre rock was obtained. It is fine-grained, dark greenish-brown in colour, with large black-green micas over an inch across, having rather irregular boundaries. In section (1939) the green tint of the mica is seen to be a surface alteration; the fresh mineral is yellow-brown in colour. There is an intergrowth of normal and abnormal mica, the latter occupying the exterior of the crystals; the mineral is distinctly biaxial. Greenish serpentine fills up the spaces between the micas; some is certainly derived from olivine, some of it is, however, fibrous, and may be derived from a pyroxene. There are abundant long, and sometimes idiomorphic prisms down to microlites of a colourless augite; it is earlier than the mica. Perofskite is abundant in largish crystals, many of which exhibit double refraction. Octahedra of magnetite are numerous, and are accompanied by a little apatite.

## III. Petrography of the Inclusions in the Pipes and Fissures.

As already remarked, inclusions of various rocks are common in kimberlite; of these Karroo dolerite and shale are the most abundant, while next in order come granite, hornblende-schist, and granulite. The last-named are nearly always garnetiferous, and by decrease in the amount of felspar and increase in the quantity of diopside pass into eclogites; many of them contain cyanite.

Before describing these rocks a short account must be given of the manner in which the plagioclase felspar and the diopside have been altered in certain of these granulites.

In the hand specimen the felspar of the rock may be found to have been partially or wholly converted into a chalky-looking material, and in many cases the inclusion has been rendered so friable by this change that it crumbles to pieces after a brief period of exposure to the weather. The smaller inclusions are more thoroughly altered, but in the larger ones there may remain an unchanged core.

In the thin section the plagioclase is found to become clouded, and under crossed nicols breaks up into an aggregate of small areas of a mineral exhibiting straight extinction and slightly higher double refraction than the felspar; the twinning in the latter is obliterated. In places the new mineral forms larger and clearer areas and shows occasionally a divergent structure. Embedded in this mass are small rhomboidal areas of calcite. The mineral has all the properties of natrolite, and has clearly been produced by the zeolitization of the lime-soda-felspars, the lime separating out in the form of calcite. In some slides the natrolite forms large clear areas and the plagioclase was probably a more acid variety; in others the alteration product is calcite, enclosed in which are small prisms of natrolite; here the felspar was probably a basic variety. This alteration has evidently been produced in the inclusion whilst it lay embedded in the kimberlite by the action of ascending heated waters in which salts or gases were dissolved. In some pipes the felspar of the inclusions is hardly altered; in others, for example at Cordaat's Kuil (Victoria West), this change is found in every one of the specimens collected, though of course with variable intensity.

In certain granulites the diopside has been altered into a cloudy grey material, most commonly along the cracks and cleavages of the mineral but quite as often independent, as seen with a low magnification, of any crystallographic structure. In this opaque-looking material there remain patches of perfectly fresh diopside.

Under a very high power the product is resolved into an extremely fine-intergrowth, if one may term it so, more or less micrographic in character, of clear diopside and a colourless

mineral with very low double refraction and refractive index. The structure is so fine that it is impossible to determine precisely what this mineral is, but it may prove to be a form of serpentine. The alteration has extended along the cleavages of the diopside, and, owing to the great differences in refractive index of the diopside and its alteration product, the extremely narrow zone of alteration appears as a darkish line. Hence the opaque character of the altered mineral when viewed with a low magnification.

This type of alteration is common in the inclusions in the pipe on Du Plessis Dam, near De Aar.

An apparently rare mode of alteration is exhibited by the boulders of granite in the lamprophyre dyke on Klein Doorn Pan, the inclusions having been partly melted by the enveloping igneous rock. In thin section (2246) the quartz grains are found to have been fused at their contacts with the surrounding minerals, and show rounded and corroded outlines like the quartz in quartz-porphyry. A colourless glass has been formed from it, and in some places a ring of augite prisms and granules. The biotite mica has been altered into a mixture of pale secondary mica, prisms of felspar, and abundant octahedra of magnetite, the latter sometimes in such quantity as to render the slide in places almost opaque. The felspars have been altered along their borders and cleavages into a granular material with low double refraction, probably a secondary felspar, containing a little pale mica; there is also some calcite present. The apatite remains unchanged.

This variety of alteration is one that is typical of inclusions of granite in basic lavas[1], but has so far not yet been recorded in connection with the kimberlite pipes and dykes in South Africa.

In a pipe on Sweet Put (Britstown) boulders showing transitional varieties from granite to gabbro can be found, but the acid rocks are too altered for sectioning. In the gabbros (1948-1949) the bulk of the rock is composed of clouded plagioclase crowded with minute granules of epidote, zoisite, and mica. Augite is altered to serpentine in places. Biotite is much clouded and altered; crystals of apatite are numerous.

Some very peculiar rocks come from the pipe on Cordaat's Kuil:—

(2226.) *Syenite*. Large porphyritic but rounded crystals of perfectly fresh microcline, also numerous small polygonal and sometimes interlocked areas of the same mineral. Plagioclase felspar is entirely altered to natrolite and calcite. Dark green augite, which is grown upon biotite. Patches of iron ore often attached to or surrounded by big areas of pale sphene.

[1] Lacroix, "Les Enclaves des Roches Volcaniques," p. 55. 1893.

(2227.) A similar rock, but having a very small amount of quartz intergrown with the felspar. The microline has again this extraordinary habit of forming isolated polygonal areas surrounded by much-altered plagioclase and probably orthoclase as well. Augite is absent.

(1923.) *Enstatite-granulite.* Du Plessis Dam. Very fresh rock, showing orientation of the minerals. Enstatite, with a very faint brownish clouded appearance, due to excessively minute inclusions arranged along the cleavage planes, forms individuals elongated in the plane of foliation of the rock. Strongly pleochroic reddish-brown biotite. Labradorite-felspar is present, forming granular interlocking areas. There are a few grains of rutile.

(2235.) *Granulite.* Cordaat's Kuil. Finely twinned labradorite-felspar showing alteration to zeolite. Colourless pyroxene in irregular areas commonly surrounded by a shell of a peculiar micrographic intergrowth of felspar and a pale almost colourless hornblende. Biotite, usually bleached till nearly colourless but full of dusty matter, especially when it is included in the felspar, where it forms narrow darkish lines. Pink garnet, more or less idiomorphic, is aggregated together; there are some grains of rutile.

(2231.) *Hornblende-granulite.* Cordaat's Kuil. Abundant irregular to granular hornblendes, showing pleochroism from yellowish to greenish brown; it forms, with extremely clouded felspar the bulk of the rock. A few grains of augite are almost completely altered to serpentine; there is a little magnetite and apatite.

(1958.) *Hornblende-augite-granulite.* Paarde Vallei, Britstown. Fine-grained rock containing rounded colourless garnet with abundant inclusions of the other minerals. Green hornblende in irregular areas moulded on the colourless augite, but showing crystal boundaries when in contact with felspar. Felspar very much altered forms the rest of the rock. Small granules of rutile are present.

(1953.) *Granulite.* Britstown Commonage. Beautiful rock composed of pink garnet, deep green diopside, and plagioclase felspar. The garnets sometimes show straight edges, but are generally irregular in outline. Iron ore is abundant in irregular masses chiefly enclosed in the garnet and diopside.

(2229.) *Granulite.* Cordaat's Kuil. Remarkable rock showing pink garnet idiomorphic in respect to felspar. The latter is mostly altered to natrolite and calcite, with numerous long well-formed prisms of zoisite and epidote; in a few places

the unaltered mineral remains; though evidently basic, it exhibits no sign of twinning. The augite is colourless, the hornblende a pale-green, and these two minerals are intergrown with the felspar (and its alteration products) and garnet in a most peculiar manner. Biotite is present, and also a little muscovite, while apatite occurs along with the garnet. Large rutiles enclosed in a shell of nearly colourless sphene are very conspicuous. The augite and hornblende form rounded or oval areas surrounded by a ring of garnet, and this in turn by felspar.

(2232.) *Granulite*. Cordaat's Kuil. Abundant garnets, more or less equal-sized. Pale diopside, usually in granules aggregated together, showing in places a passage into dark-green aegirine-augite. Sometimes there has been a secondary enlargement of the augite, the new mineral being pleochroic aegirine; seeing that the felspar has been largely altered to natrolite, a source for the sodium in the aegerine is at once suggested. There is a little green hornblende intergrown in places with the augite. Rutile is abundant, surrounded by a wide border of nearly colourless sphene; it is associated with a little cyanite. The felspar forming the groundmass is much altered in places, and seems to be probably andesine, for its refractive index is a little higher than that of Canada balsam.

(2242.) *Cyanite-granulite*. Brandewyn's Kuil, Victoria West. Large garnets, surrounded by a narrow shell of nearly colourless material. Cyanite forms large irregular plates down to small irregular granules or prisms, and it is an important constituent of the rock. Pale brown biotite in rounded areas. Felspar, a basic variety without twinning, forms about one half of the rock, altering in places to a yellowish fibrous zeolite. Rutile in large grains is very conspicuous as inclusions in the garnet and cyanite. Very minute octahedra of greenish spinel are most abundant.

(1922.) *Cyanite-granulite*. Du Plessis Dam. A well-foliated light-coloured rock. The crystals of cyanite show straight sides and more or less rounded, less rarely jagged, ends. The mineral is colourless and shows occasional twinning; in places round the edges it is altered to a colourless slightly fibrous nearly isotropic substance. Small prisms of labradorite felspars are aggregated to form patches. The groundmass of the rock consists of the peculiar alteration of diopside recorded previously. Minute octahedra of pale-greenish spinel are present, but not in quantity.

(1924.) *Cyanite-granulite*. Same locality. A coarser rock showing mineral banding. The diopside shows a meshwork of alteration proceeding through the crystals; the pink garnets are

altered both externally and along cracks to a greenish-yellow fibrous material. The cyanite is less abundant in the slide than in the hand specimen, and is found as small prisms with rounded ends included in the garnet and occasionally in the diopside. There are also large grains of rutile, while a few spaces between the constituents of the rock are filled with quartz, calcite, tufts of actinolite, prisms of cyanite and octahedra of greenish spinel.

(1956.) *Cyanite-granulite.* Paarde Vallei, Britstown. Small colourless garnets, irregular as a rule but showing faces when in contact with felspar. Grains of colourless pyroxene, quite unaltered. Small irregular areas of felspar, probably oligoclase. Cyanite in longish prisms in the felspar and diopside, or more commonly in little rods and grains arranged end to end or in rows, but separated from one another by quartz.

(1942.) *Cyanite-eclogite.* Blaauwbosch Puts, Britstown. Colourless irregular garnets. Diopside, colourless but almost entirely changed to grey opaque material; full of long and very narrow prisms of cyanite arranged with more or less parallelism or in sheaves. Some of the stouter individuals show good crystal outlines.

(2234.) *Eclogite.* Cordaat's Kuil. Idiomorphic pink garnet; green diopside with irregular boundaries and sometimes showing a kind of intergrowth with the felspar. The latter is altered to cloudy natrolite with some calcite. Iron ore forms large irregular patches, and with it occur big rutiles, some biotite, and a few grains of cyanite.

(1941.) *Eclogite.* Blaauwbosch Puts, Britstown. Pink garnets surrounded by and having cracks filled with a chloritic mineral. Diopside much altered in places, the greyish product being pinkish by reflected light. Felspar forms patches between these minerals, and is sometimes included in the garnet. It is untwinned, but is clearly a very basic variety. Rutile is abundant in very large grains.

(1944.) *Eclogite.* From the same locality. This rock is interesting for the bulk of it is composed of garnet with some diopside, a very little untwinned plagioclase felspar, and small areas of olivine now pseudomorphed by large plates of pale brownish talc. The rock, therefore, tends to form a link with the peridotites.

(2280.) *Eclogite.* Markt, Prieska. The diopside is altered on its edges and along cracks into a mixture of serpentine and carbonates. The garnets are changed along cracks and surrounded by a brownish material with which biotite is associated; probably the latter is of secondary origin. Large grains of rutile.

(2281.) *Eclogite.* Same locality. A remarkably handsome rock consisting of green diopside, pink garnet, and deep brown rutile. The latter is abundant in irregular areas, and is sometimes as large as the garnet. There is a small amount of untwinned basic-felspar slightly altered at the contact with the other minerals.

## *The Origin of the Granulites.*

The origin of these peculiar rocks forms a problem which requires for its solution the examination of more material and the carrying out of numerous chemical analyses. One point is clear, however, that the granulites form a distinct group by themselves, ranging from acid varieties to the basic eclogites. Their relationship to the granites and gabbros is not clear, but is certainly not a close one; the peculiar microcline rocks from Cordaat's Kuil with semi-granulitic structure form a sort of connecting link. The eclogites again do not seem to have any marked affinities with the ultra-basic lherzolites and saxonites, as pointed out some time ago,[1] though there are a few linking types known.

The granulites possess many characters which ally them to rock that have been recrystallised by thermal metamorphism; for example, firstly, the well-developed granulitic structure, secondly the abundance of garnet sometimes with inclusions of felspar, etc., thirdly the presence of cyanite, rutile, sphene, and sometimes spinel and corundum.

It therefore seems not unlikely that these granulites represent intensely metamorphosed igneous and possibly sedimentary material, and that they were produced at great depths in the earth's crust. They do not closely resemble any of the Prieska granulites however, though it must be noted that in the latter the garnet is sometimes nearly idiomorphic, and that they contain sphene, and in places silicates of alumina such as cyanite, andalusite and sillimanite. It is difficult to predict how the Prieska granulites, for instance, would be transformed at great depths; hornblende, however, would probably be changed to pyroxene, and sillimanite and andalusite to the stable form cyanite. It is notable that in the eclogites the pyroxene contains chromium and that the presence of the rutile and sphene indicates a considerable amount of titanium.

In no respect, however, do these granulites and eclogites exhibit any affinities to kimberlite, or to the lamprophyres and melilite-basalts, even the brown micas in the former never possess the abnormal absorption frequently seen in those of the latter, and there seems not the slightest justification for considering them as " concretions " or " segregations " formed in the blue-ground.

[1] Annual Report for 1906, p. 157.

# NOTES ON A JOURNEY TO KNYSNA.

BY A. W. ROGERS.

A visit was made to the Knysna district in March for the purpose of inspecting the lignite deposits recently opened up in the forest-covered area eight miles north-east of the town of Knysna. At the same time the opportunity was taken of seeing some prospecting work done in the melilite-basalt of Spiegel River, and of making a further examination of the fossiliferous beds of Uitenhage age along the shore of the Knysna estuary at Brenton.

## *The Melilite-basalt of Spiegel River.*

This occurrence is described in a previous Report.[1] Prospecting holes have been opened in the hope of finding diamonds, though there was no reason to suspect the presence of that mineral. The only facts of interest got from the holes are: (1) The very unequal depths to which the melilite-basalt is decomposed at spots quite close to one another, and (2) the presence of aggregates of barytes along ill-defined joints in the decomposed rock.

In its fresh state the rock is almost black, with glassy-looking crystals of olivine scattered through it; at one hole the rock is decomposed to a depth of 18 feet, into a red clay with white specks of soapy hydrous magnesium silicate retaining the shape of the original olivine crystals. How much further the rotten rock extends is not known, for the hole was abandoned at the depth mentioned. Within a few yards of this hole the basalt forms unweathered outcrops or the fresh rock is only covered by a few inches of brownish disintegrated rock and soil.

The barytes aggregates were met with in a joint in the decomposed rock six feet from the surface. The very complete analysis of the fresh rock made by Mr. J. Lewis and given in the Ann. Rep. Govt. Com. for 1903, p. 51, shows that ·06 per cent. of barium oxide was present in the sample; so the lumps

[1] Annual Report for 1898, p. 62. In this description the diameter of the basalt mass is said to be about 100 *feet*, a mistake for *yards*.

of barytes probably represent the barium salts originally scattered through the fresh rock. It is worth noting that barytes occurs in the central pipe of the Saltpetre Kop group (Report above quoted, p. 59).

With the aid of several small artificial exposures a better measurement of the size of the basalt area was obtained. It seems to be somewhat pear-shaped in outline; the axis lies north-west, and is about 300 yards long; the widest part is near the north-west end, where the basalt was traced to 220 yards. There is no indication of a change of character in the rock near the periphery or in any other part of the area.

### *The Uitenhage beds of Brenton.*

Along the west shore of the Knysna estuary, on the farm Brenton, there are fossiliferous limestones and clays exposed at intervals for nearly a mile. The exposures are often poor, and they vary from time to time owing to the slipping down of the soil from the steep slope above them.

The beds lie horizontally, and the lowest exposed rock is a conglomerate of quartzite pebbles set in a white sandy matrix, a rock which is very like the usual white Enon conglomerate; this bed is only exposed for a few yards along the shore below high-water mark. It is separated by a few inches of sandy clay from a shelly conglomerate which is from 2 to 3 feet thick. This conglomerate has smaller pebbles in it than the lower one, and the matrix is largely made up of broken shells.

*Trigonia* is the only genus that could be recognised amongst the shell fragments, and two fairly perfect specimens of a shell very like *T. rogersi*, Kitchin, were got from this rock.

Above this shelly conglomerate a thickness of some 15 feet of clays, sandy clays and friable shales, all grey in colour, are exposed at various spots above high water-mark. The fossils in those beds are usually very fragile, one of the most frequent is *Ptychomya complicata* (Tate) or a shell like it. There are a few calcareous nodules in these grey beds, and they have yielded most of the fossils as yet obtained from the locality. In a small collection obtained there in 1905 Dr. Kitchin recognised *Acanthodiscus, sp.*, *Belemnites, sp.*, and *Trigonia holubi* (?) Kitchin.

The number of these nodules obtainable at any one time is very small, but they are washed out of the clay or fall out as the surface of the steep slope crumbles away. This year a few more pieces were found. They contain *Nautilus*, a shell like *Meretrix uitenhagensis* Kitchin, *Perna* sp., spines of *Cidaris*, or an allied echinoderm, and stem joints of a crinoid like *Pentacrinus*. There are also small lamellibranch shells of an undetermined form, which is also found in the Uitenhage district, and many fragments of other undetermined species.

The list of species would undoubtedly be very greatly increased by continuous collecting.

The fossils hitherto obtained show that the fauna of these beds is not identical with that of the Sunday River beds in the Uitenhage area, but very like it, and the similarity justifies the inclusion of the Brenton beds in the Uitenhage series.

An interesting question, which is not yet solved, is that of the relation of these marine beds at sea level to the conglomerates seen rising to much higher levels a few miles to the north on both sides of the river,[1] and also to the east and west.

## THE KNYSNA SERIES.

In Prof. Schwarz's description and map of the Knysna district[2] certain sandy deposits are classed as Recent beds or drift sand. The line of the new railway to the forest traverses one of the sand areas delineated in the map quoted, and also another to the north of it. The sections exposed in these two areas are similar; they show yellow and reddish sand, either coarsely false-bedded or without lamination, and they probably belong to one and the same formation. They can be called the Knysna beds. Along the railway they occur at levels of from about 700 to 1,300 feet above sea level.

Several years ago lignite was found in a deep, heavily-wooded kloof N.N.W. of the place where Parks Station stands, but only recently has work been done with the object of finding the extent of the deposit and its value directly as fuel or as a material for briquettes. The lignite at the time of my visit was exposed at seven places between points N.N.E. and N.W. of Parks Station, and it has since been met with in a shaft which at that time was down through 47 feet of yellowish-red sand at Parks Station. The lignite is interbedded with the sand.

The boundary of the deposit is difficult to trace because it is largely covered by forest. The railway cuttings and an outcrop of Table Mountain sandstone, 1½ miles east of Parks Station, furnish the data by which the limits of the Knysna beds of this area were laid down on the accompanying plan.[3] The limit to the west is quite uncertain.

The thickness of the beds in this area is not less than 206 feet at one place, near a shaft north of the station, put down at a spot 150 feet below the level of the top of the shaft near the station, for the bottom of the Knysna beds was found at 56½ feet in the former shaft.

[1] Annual Report, Geological Commission, for 1899, p. 58.

[2] *Loc. cit.*, p. 62, and Annual Report for 1905, p. 75. and Map of Coast Plateau issued with this Report.

[3] I am indebted to Mr. H. Noren, Manager of the Railway, for the plan of the line and the heights of the milestones. Other vertical measurements in this Report are from aneroid readings.

This shaft gave the most continuous section available at the time of my visit, it is as follows:—

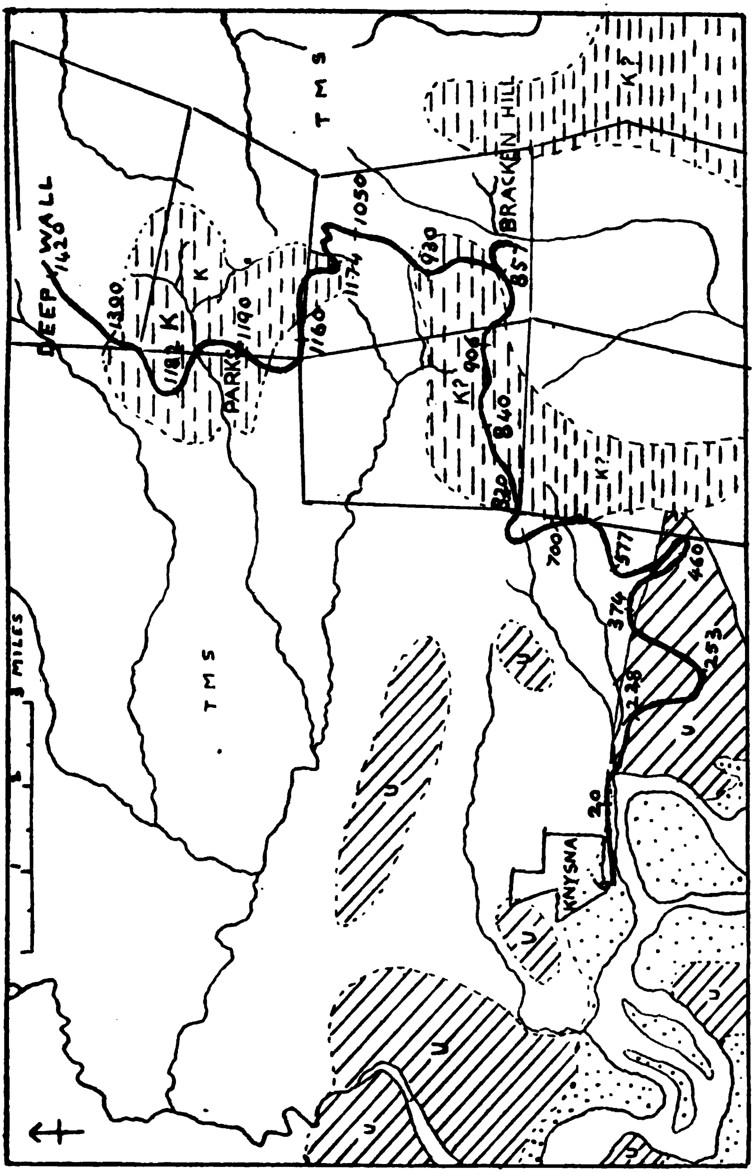
| | ft. | ins. |
|---|---|---|
| Yellow sand ... ... ... ... ... ... ... ... ... ... ... ... | 3 | 0 |
| Lignite ... ... ... ... ... ... ... ... ... ... ... ... ... ... | 8 | 0 |
| Brown sand ... ... ... ... ... ... ... ... ... ... ... ... | 1 | 6 |
| Lignite ... ... ... ... ... ... ... ... ... ... ... ... ... ... | 6 | 6 |
| Brown sand ... ... ... ... ... ... ... ... ... ... ... ... | 1 | 6 |
| Lignite ... ... ... ... ... ... ... ... ... ... ... ... ... ... | 3 | 6 |
| Black laminated lignitic sand ... ... ... ... ... | 31 | 0 |
| Conglomerate ... ... ... ... ... ... ... ... ... ... ... | 1 | 6 |
| | 56 | 6 |

The conglomerate rests on sheared quartzite belonging to the Table Mountain series, and consists of small pebbles of quartzite in a sandy matrix coloured dark brown by lignite. The only fossil leaves yet found in these beds came from the brown sand in this shaft. They are lanceolate leaves and are rather thick, some have smooth edges others are slightly serrated, but they are not well enough preserved to show the venation. Botanists to whom they were shown declined to express an opinion as to their relationships. Fossil wood, of which long pieces are found in the lignite and in the brown sand at all the places where sections have been opened, is frequently seen; Prof. Pearson, of the South African College, cut some thin sections from it and found that it belongs to coniferous trees. Up to the present time this wood and the leaves are the only fossils recognised from the Knysna beds.

The lignite and sands are best exposed for examination in two drives in the deep kloof N.N.W. of the station. The one on the left bank of the stream is 150 feet below the station, and in it 8 feet of lignite, with a bed of brown sand about one foot thick in the middle, are exposed. The greater part of the lignite is a brown structureless substance, but in places it becomes laminated owing to the presence of wood fibres and lumps of wood lying horizontally in it. In addition to the thick layer of brown sand in the lignite there are ill-defined sandy streaks in it which pass into ordinary lignite. These sandy patches are thin and short in section. The brown sand in this and the section described below contain small lumps of yellow resin.

The drive on the right bank of the same stream is situated about 30 feet higher than the one on the left bank.

At the mouth of the cutting two feet of lignite are overlain by sand and brown sandy clay, which passes laterally into sand and then again into clay, and this clay ends off as a tongue in the lignite bed, which thickens to nearly four feet at the mouth of the drive itself. The lignite and brown sand




Map showing position of the Knysna beds (K) at Parks. The area occupied by the Table Mountain series is left blank. The Uitenhage beds (U) are indicated by diagonal lines and the Knysna beds by broken horizontal lines. The geological lines on this map are taken from Schwarz's field maps, with corrections along the railway line (thick black line; figures are heights in feet at the milestones).

are overlain by yellowish and reddish sand showing traces of lamination and false bedding, and above this paler sand there lies brown sand without lamination.

The lignite probably extends over the greater part of the area occupied by the Knysna beds near Park Station; whether it occurs also in the other areas of false-bedded yellow-red sands is not known.

With regard to the age of the beds, it is probable that they were formed during some part of the Tertiary period, but the evidence at present available is not sufficient to settle the question. Both the sandy beds and the lignite are different in appearance from any of the sands and lignites known to me from the Uitenhage series, and the fossil leaves differ entirely from anything yet found in the latter group.

The position and thickness of the beds and the extent to which they have been cut into by the streams seem to exclude them from the recent formations.

The lignite must have accumulated under water or in a swampy place, but the upper reddish-yellow sands, frequently without lamination but at places false-bedded, would seem to have been deposited on the land and not under water.

The Knysna beds reach a height of 1,300 feet above sea level. The country they occur in is part of the high-lying coastal plateau on which the higher points, such as Groot Kop, near Parks, rise to a height of between 1,500 and 1,600 feet. It is unlikely that these beds would have been formed at such an elevation in the proximity of the coast, and it is probable that they were laid down when the country stood some 700 feet lower with regard to the sea-level than it does now. It is also unlikely that the coast plateau has been covered by the sea since these beds were formed, for they do not contain any evidence of marine life, and, had the area been exposed to the waves, such a soft formation would surely have been swept out of the hollows in the hard Table Mountain series in which it was deposited.

# THE TYGERBERG ANTICLINE IN PRINCE ALBERT.

BY A. W. ROGERS.

In a paper read before the Geological Society of South Africa, in 1906, Dr. Sandberg brought forward evidence to show that the ridge of Witteberg beds, called Tygerberg, is not an anticline, as had been supposed by previous observers,[2] but that it is the northern end of an extension of the Sand River Mountain anticline bent over northwards and reposing in an inverted position on the Dwyka and Ecca series, thus being in fact a syncline.

Prof. Schwarz, who surveyed the area in 1903, controverted Dr. Sandberg's interpretation of the facts in a later paper,[3] but Dr. Sandberg still maintained[4] that some important points had been overlooked by the previous observers, and that the "recumbent" fold existed.

In order to see the evidence I spent a week in the country between Prince Albert Village and the east end of Tygerberg, for if the new interpretation could be verified similar structures might have been missed by the survey in other parts of the southern mountainous country.

The important points to be determined were: (1) The structure of the ridge of Witteberg beds of Tygerberg itself; (2) the determination of the beds in Sand River Valley, and (3) to find out the nature of the lenticles of quartzite within the Dwyka series near Tygerberg which Dr. Sandberg regards as "lambeaux" of Witteberg beds separated from the main mass of Tygerberg by denudation acting on highly folded strata.

There are some other matters which might be gone into, but of these only one need be dealt with. On p. 87 of his first paper (Trans. Geol. Soc. S.A., vol. IX) Dr. Sandberg says:— "Going south through the Zwartberg Poort we first met with the Witteberg quartzites overlying the Dwyka, just south of Prince Albert; this is the inverted limb of the anticlinal root. Further south again the lower Dwyka and the conglomerate overlie the Witteberg quartzites, always with the typical shales

[1] C. Sandberg, "Transactions Geological Society, South Africa," vol. ix. p. 82.

[2] Map and section attached to Parliamentary Report G. 45 –'93, by A. R. Sawyer; Schwarz, Annual Report Geological Commission for 1903, p. 90.

[3] *Geological Magazine*, 1907, p. 487.

[4] *Geological Magazine*, 1908, p. 311.

separating the Dwyka from the Witteberg quartzites."[1] Examining the field sheets and notes of that area, made by myself in 1897, I could find no mention of the occurrence of the Dwyka series south of the quartzite hills behind Prince Albert, nor was it found by Mr. Schwarz at a later date; I therefore searched for it again but failed to find it. Prince Albert village stands on a line drawn west through the Sand River anticline, but the Witteberg beds of that anticline can be seen to disappear under the Dwyka just west of the first stream east of the Prince Albert valley; the steep reversed dips of the northern limb of that anticline are continued in the Dwyka series past Prince Albert village.

(1) An examination of the Tygerberg ridge, with the exception of the easternmost two miles which I did not visit, proves that in every part seen the anticlinal structure is visible. Where streams have cut through it the anticlinal fold can be seen throughout until the Witteberg beds disappear under the Dwyka both to the north and the south. The dips vary, and at two places at least, faults cutting the Witteberg and Dwyka obliquely (strike of beds nearly E.-W.; course of faults about E. 15° S.) obscure the main structure slightly. The west end of the ridge is very well exposed, and the outcrops of the harder beds show most distinctly how the Witteberg beds disappear here by the westward dip of the axis of the anticline. The complications mentioned by Prof. Schwarz, on p. 91 of the '03 Report, do not affect the main anticline, but concern the stratigraphical position of certain brownish impure quartzites to the north.

After going through all the transverse ravines and walking along the axis of the anticline, often a bare mass of white quartzite dipping on either hand below the Dwyka, for hundreds of yards continuously, it was difficult to understand why the anticlinal structure should ever have been doubted.

Where the river from Carolus Kraal has cut through the ridge on Sleutel Fontein there are two anticlines, which overlap in plan for some 900 yards and which are separated by a lateral stream from the north-east following the course of a fault or fold with E. 15° S. course. The rock of the stream bed is concealed by debris, and so is that of the valley sides where the stream lies between the two anticlines, so I could not see whether the Dwyka series occurs there. The two quartzite outcrops are separated by nearly 300 yards of covered ground. The stream from Carolus Kraal exposes the structure of the northern quartzite, a very sharp anticline with both limbs dipping southwards, the northern one at about 80° and the

[1] The sections fig. 1 in Fig. 2, Plate XXI. attached to this paper, and Fig. 2 in *Geological Magazine*, 1908. p. 312, illustrate the above statement.

southern 70°. The southern quartzite ends as an anticlinal surface with easterly inclined axis just in the bed of the river.

The difficulty in explaining every outcrop north and south of the main ridge of Tygerberg is due to the fact that there has been faulting and slipping away of the beds immediately above the thick white quartzites. It seems to me that Prof. Schwarz has exaggerated the number of places where the Dwyka series lies at a low angle near these white quartzites, but that his description of the quartzites as appearing to have been forced through the Dwyka series along the anticlinal axis is correct.

In this connection it is most important to retain a definite horizon as the top of the Witteberg beds; the Survey has taken that horizon to be the top of a thick band of white quartzites, while Dr. Sandberg includes the lower part of what we call the Lower Dwyka shales in the Witteberg series. Either choice is arbitrary; but in discussing the structure of a limited area the change from one to the other only causes confusion. Thus the brownish quartzites lying north of the west end of Tygerberg would be included in the one or the other series according to where the base of the Dwyka is drawn. These quartzites and accompanying shales form an anticline with both limbs dipping southwards, the north limb more steeply than the southern. Immediately south of these rocks, for a distance of several hundred yards west of the gap through which the main road now passes through the main Tygerberg ridge, there seems to be no tillite between this anticline and the main ridge; dark shales with limestone bands were the only rocks found, and they probably belong to the Upper Dwyka shales; the same beds, with the characteristic white weathering rock, occur east of the gap also, but here the tillite comes in also, and can be followed continuously to Klein Sleutel Fontein, being joined near the Tygerberg River by the tillite north of the quartzite and shale anticline. There are evidently two faults west of the gap, one immediately north of the white quartzite anticline and the other south of the quartzite and shale anticline. Towards the east these faults die out, and south-east of Tygerberg homestead there may be the whole succession, but probably part of the lower Dwyka shales are missing here. On the south flank of the main ridge, where the Upper Dwyka shales lie against it on the north, the lower shales are missing for some distance, and the tillite rests directly on the white quartzite.

Near the Poort of Tygerberg River the succession is much more complete on the south flank than on the north, where the lower shales are missing, at least in part.

At Klein Sleutel Fontein the succession is broken on the south side by a fault along which the Ecca beds are let down against the white quartzites, the Dwyka tillite apparently

coming in again further south, but I had insufficient time to settle this point.

The upper boundary of the Dwyka series is as important as the lower in deciding the structure of this area, and it is far less disturbed, doubtless because it happens to be drawn on a horizon where, excepting the thin chert bands, the rocks have fairly uniform characters through a considerable thickness. The regularity of its position, the northern limit of the anticline dipping vertically or nearly so, while the southern limit is less highly inclined, gives the country the appearance of a geological model when seen from the highest point on Tygerberg. The dislocations described above are confined to the area enclosed within the elongated oval outcrop of the White Band, and do not appreciably affect its regularity.

(2) The Sand River runs in a longitudinal valley between the Tygerberg anticline and that of the Sand River Mountain. The valley in the neighbourhood of Tygerberg is wide, and as the river bed lies nearer the southern anticline of Witteberg beds than the northern the southern slope is the greater. The northern slope is very gentle, and looking northwards from Sand River Mountain one can see that the slope is made by the confluence of several flat alluvial cones, each heading in a kloof in the line of hills made of the lower Ecca beds. This plain has practically no outcrops, but there are a few along the river bed, and these are sandstones and shales of the same character as those exposed north of Prince Albert Village, where the Sand River valley is less flat. Near the farmhouse half way between the village and Tygerberg the Ecca beds are again well exposed. If there ever had been an outlier of Witteberg beds, the remnant of the connecting link between the root and crown of Dr. Sandberg's recumbent fold,[1] in this valley, there would surely be signs of it, as the valley has been excavated in the old high level terrace covered with boulders of Witteberg quartzite still making a prominent feature on the northern flank of the Sand River Mountain. These quartzite boulders are found at intervals on the gentle slope north of the river bed, and they can certainly be regarded as relics of the terrace which once stretched over this slope. The terrace is part of the terrace which stretches far along the north side of the Zwartbergen and of which very prominent outliers are seen near the village. Elsewhere it is found that though the terrace passes over hard and soft rock alike, the streams which have cut into it always work along the soft bands, and only traverse the hard ones at right angles. This behaviour of the later streams is well seen between Prince Albert and Matjesfontein.

[1] Such outliers are represented in figs. 1 and 2 of Fig. 2, Plate XXI. of Dr. Sandberg's paper.

(3) Particular attention was paid to the isolated bands or lenticles of quartzite lying within the Dwyka tillite and illustrated in Fig. 6, and also Fig. 11 of Fig. 2 on Plate XXI of Dr. Sandberg's first paper, and in Fig. 3 of his paper in the Geological Magazine.

In seeking for an explanation of the occurrence of white quartzite in the Dwyka series, Dr. Sandberg seems to assume that the fact of a rock being a white quartzite means that it is part of the Witteberg series, but bands and lenticles of such rock have been found in the Dwyka series elsewhere in the south of the Colony.[1]

The quartzite lump figured by Dr. Sandberg and described on p. 85 of his first paper, is surrounded by tillite without the intervention of any shales as stated in Fig. 11 of Fig. 2, plate XXI of his paper. A search for a clear exposure of the contact of the quartzite and tillite revealed the fact that on the north-western side of the quartzite a passage from one rock to the other exists; the yellowish-white quartzite becomes darker in colour, more gritty, and contains small pebbles of granite of the same kind that occur in the blue tillite. The transition from quartzite to tillite of the usual kind takes place within six inches, and there is no divisional plane between them. Such passages are naturally not often exposed, for the difference in character between the quartzite and tillite makes the junction particularly liable to be covered by debris from the quartzite. Another very good exposure of the same kind of passage from the quartzite to tillite is to be found south of the main ridge of Tygerberg, about a mile west of the poort of Tygerberg's River; it is exposed in the bed of a ravine.

Were these quartzites originally part of the Witteberg series, such passages into tillite could not exist and there must have been slickensided surfaces on the quartzites, like those which are magnificently developed on the great bare dip slopes of the main ridge on the western part of Klein Sleutel Fontein. These slickensides have obviously been made by the movement of one layer of rock over another during the sharp bending they have undergone.

After a careful examination of what seemed to me the most important parts of the evidence, I came to the conclusion that the recumbent fold described by Dr. Sandberg does not exist, but that Tygerberg is an anticline, as described by previous observers.

[1] Annual Report Geological Commission for 1897, p. 67; for 1903, p. 23.

# INDEX.

# CAPE OF GOOD HOPE.

## DEPARTMENT OF AGRICULTURE.

# FOURTEENTH

# ANNUAL REPORT

OF THE

# GEOLOGICAL COMMISSION.

## 1909.

*To be Presented to Parliament, 1910.*

CAPE TOWN:
CAPE TIMES LIMITED, GOVERNMENT PRINTERS.
1910.

[G. 34—1910.]
£43-11-10

B'401.1600,8.'10.
C.T.Ltd.—B.520

# GEOLOGICAL COMMISSION OF THE COLONY OF THE CAPE OF GOOD HOPE, 1909.

## MEMBERS OF THE COMMISSION.

THE RIGHT HON. JOHN XAVIER MERRIMAN, M.L.A.

THOMAS MUIR, C.M.G., LL.D., F.R.S.
Superintendent-General of Education.

THOMAS STEWART, M.I.C.E., F.G.S.

ATHELSTAN HALL CORNISH-BOWDEN, Surveyor-General.

FRANCIS EDGAR KANTHACK, A.M.I.C.E., Director of Irrigation.

*Secretary*—
THEODORE MACKENZIE.

## SCIENTIFIC STAFF.

*Director*—
ARTHUR WILLIAM ROGERS, Sc.D., F.G.S.

*Geologist*—
ALEX. LOGIE DU TOIT, B.A., F.G.S.

Geological Commission,
South African Museum,
Cape Town, August 16th, 1910.

SIR,

I have the honour to forward the Annual Report of the Geological Commission for the year 1909.

It is a matter for regret that financial exigencies have compelled the Commission to curtail somewhat the operations in the field. They are pleased, however, to add that the amount of work prepared is extremely creditable.

The question of the policy to be pursued in reference to the future conduct of the geological survey of the Cape Colony being under your consideration it is not necessary to discuss it in this place

It only remains for me to express on behalf of the Commission our sense of the devotion and zeal displayed by Dr. Rogers and Mr. du Toit under somewhat discouraging circumstances.

I have, etc.,

JOHN X. MERRIMAN,
Chairman.

The Hon. the Minister
of the Interior.

GEOLOGICAL SURVEY

OF THE

COLONY OF THE CAPE OF GOOD HOPE.

---

# DIRECTOR'S REPORT FOR THE YEAR 1909.

---

During the past year the survey was carried on in Prieska, Kenhardt and Carnarvon in continuity with the work done during 1908. Mr. du Toit spent three months in the southern part of those districts before he went on five months' leave, and I was occupied in the northern portion for six months. The results of those journeys are presented in one report.

The main part of the work concerns the very old formations grouped under the Kheis series and the granitic rocks associated with them. An improvement in the classification of the northern formations has been made possible by the inclusion of the Wilgenhout Drift beds, first examined in Gordonia in 1907, with the Kheis series. Another group of rocks first met with in 1907, the Koras series, is continued in the Kenhardt district, but beyond fixing its age as greater than that of the Karroo formation no advance has been made towards its correlation. Unfortunately the past year's work threw no fresh light on the difficult question as to the correlation of the Zwart Modder beds with one or other of the Griqualand West series on the east of the Kalahari.

A considerable part of the area referred to above is represented on the coloured sheets 32 and 40, which are in the press.

At the end of November, owing to a request from the General Manager of Railways for a report on the coal prospects in Wilgebosch Kloof and the adjoining country in Sutherland, Fraserburg and Beaufort West, I went to that area for four months and examined a considerable tract of country of which a geological

survey had not been made before. It was intended to complete sheet 13, but that proved to be impossible without fresh transport. As most of this work was done in 1910 the account of it will appear in the next Annual Report.

This diversion interrupted the preparation of the present Report and delayed its completion.

Visits were made to Kimberley and Port Elizabeth for the purpose of examining the rocks brought up from the deep bore-holes at Dubblede Vlei and Zwart Kops; of these, the description of the latter alone can be published at present.

The Commission is indebted to the Surveyor-General for assistance in various ways, and in particular to Mr. J. J. Bosman, Director of the Secondary Triangulation, for the position of numerous points, which have greatly facilitated the reduction of the maps for publication.

The thanks of the Commission are due to the North-Western (Cape Colony) Prospecting Syndicate and the Zwart Kops Syndicate respectively for leave to examine their records.

Sheets 33 and 41 of the Geological Map were issued during the year. Sheets 32 and 40 are in the printers' hands, and sheet 11 is being prepared for the printer.

One part of the Annals of the South African Museum dealing with fossils, Vol. VII., Part 3, containing six papers by Dr. R. Broom, was issued during the year.

The following papers, etc., by the Staff were read or published during the year:—

"De jongste geologische onderzoekingen in het Noorden van de Kaap-Kolonie," by A. W. Rogers (vertaald door E. C. Abandanon). Tijdschrift van het Kon. Ned. Aardrijks-Kundig Genootschap, Vol. XXVI., pp. 416-427.

"The evolution of the river system of Griqualand West," by A. L. du Toit. Trans. Roy. Soc., S.A. Vol. I., pp. 347-361. (Jan., 1910.)

"An Introduction to the Geology of Cape Colony," 2nd edition, by A. W. Rogers and A. L. du Toit, London, 1909.

ARTHUR W. ROGERS.

## GEOLOGICAL COMMISSION.

### General Abstract of Receipts and Disbursements for the Year ended 30th June, 1909.

| | £ s. d. | £ s. d |
|---|---|---|
| To Balance as per Cash Book, 1st July, 1908 .. .. ... ... | | 366 17 8 |
| „ Balance Advance (A. W. Rogers) ... | | 3 18 4 |
| „ Government Grant ... ... ... | 1,500 0 0 | |
| „ Sale of Donkeys ... ... .. | 45 2 6 | |
| „ do. Maps ... ... .. | 6 0 6 | |
| | | 1,551 3 0 |
| „ Advances (Current), repaid by vouchers | | 190 0 0 |
| | | £2,111 19 0 |

| | £ s. d. | £ s. d. |
|---|---|---|
| By Salaries ... ... . ... | 1,000 0 0 | |
| „ Allowances (Personal) ... .. | 263 8 9 | |
| „ do. (Horse) ... .. . | 32 16 0 | |
| „ Transport ... ... ... ... | 49 18 3 | |
| „ Postages .. .. . | 23 14 3 | |
| „ Printing, Books and Magazines .. | 23 7 7 | |
| „ Rock Sections ... ... .. | 21 15 7 | |
| „ Boys' Wages ... ... ... | 48 1 6 | |
| „ do. Food ... ... .. | 26 11 4 | |
| „ Purchase of Donkeys . ... | 62 0 0 | |
| „ large Scale Maps .. ... .. | 63 10 0 | |
| „ Equipment and Maintenance ... | 20 11 11 | |
| „ Description of Specimens . .. | 60 0 0 | |
| „ Printing Annals . ... .. | 113 14 8 | |
| „ . ... | 10 2 0 | |
| „ ... .. | 9 3 6 | |
| „ Report .. | 25 4 5 | |
| „ Horse Purchase Loss ... .. | 11 13 9 | |
| „ Analyses ... ... ... . | 3 14 0 | |
| „ Miscellaneous .. .. . | 2 17 0 | |
| | | 1,872 4 6 |
| „ Advances made ... . .. | | 190 0 0 |
| „ Balance as per Cash Book ... .. | | 49 11 6 |
| | | £2,111 19 0 |

(Signed) THEODORE MACKENZIE, Secretary.

I hereby certify that the above Account has been examined under my directions and is correct, and that the balance agrees with that shown in the Bank Pass Book.

(Signed) WALTER E. GURNEY,
Controller and Auditor-General.

Cape Town, 7th October, 1909.

# REPORT ON THE GEOLOGY

OF PARTS OF

# KENHARDT, PRIESKA, VICTORIA WEST AND CARNARVON.

---

BY A. W. ROGERS AND A. L. DU TOIT.

# GEOLOGICAL SURVEY
## OF PARTS OF
# KENHARDT, PRIESKA AND CARNARVON.

By A. W. Rogers and A. L. du Toit.

The region described in the following pages extends from the Orange River below the Prieska boundary to Upington and southwards to near Carnarvon. The Hartebeest and Zak Rivers form the western limit from Staan-still-en-afspring on the Zak to Vyf Beker on the Hartebeest, though a small area was gone over west of the river near Kenhardt. From the farm named on the Zak the boundary runs through Verneuk Pan past Zwart Kop, Hartog's Kloof, Boter Leegte and Meintjes Kloof to the neighbourhood of Carnarvon, thence to Victoria West and Van Wyks Vlei, across the Kaaien Bult to Nels Poortje, along the south-western flank of the Kaaien hills to Karree Leegte and across the hills to the Orange River on Uit Draai.

The chief hills in the district are those formed by the Kaaien beds near the Orange River, which rise about 900 feet above the river. They are rough, steep sided hills dissected out from a continuous range which trends in the direction of the strike of the beds. The summits are rounded or flattened, and the range is cut through by two transverse valleys in this area, Vaal Kloof and the valley from Boks Puts. Where the strike changes, as on Stof Gat, Kalk Werf, Weg Draai and Uit Draai, the hills form spurs more or less closely connected with the main range. The larger strike valleys in the main range are underlain by granite or gneiss intrusions, and these rocks completely separate large bodies of the Kaaien beds from the main mass on its south-western side. A fault separates an unconformably overlying strip of the Koras volcanic rocks and an eastern branch of the Kaaien beds from the main range on Zaals Kop and Kalk Werf; but this fault, though coincident with the strike of the Koras beds cuts across the Kaaien strike obliquely. The Koras beds here occupy a valley, but whether this valley is entirely due to erosion acting on less resistant rocks, or whether it is partly a feature of pre-Koras date emphasized by faulting, is not clear.

In this area there is no direct evidence as to the age of the main features of the Kaaien hills, but as outliers of the Dwyka have been found in the valleys near the Orange River below Ezel Rand, and Piljaar's Poort a few miles further up stream, it is likely that the chief transverse and longitudinal valleys are of pre-Dwyka age.

To the south-west of the Kaaien range lies a very wide area of little relief. The southern part is still occupied by the Dwyka series and its outliers, but the northern consists of granite, gneiss, and various granulites and schists, fragments of a presumably once continuous mass of sediments and volcanic rocks belonging to the Kheis series; the granitic rocks are intrusions as regards these fragments, which have probably been separated from each other by denudation acting on an intensely folded mass already divided up into partly disconnected blocks by the intrusion of the granite.

The hills in the northern area are low and scattered. The less foliated or even massive granites give rise to tors, kopjes which appear to be made of huge blocks piled on one another. Occasionally a rock consisting largely of metamorphic minerals, such as the cordierite-rock near Olyvenhout Drift, makes similar tors; but generally the larger streaks of more resistant schists of metamorphic origin appear in ridges or low rises amongst the granite and gneiss. The gneiss only makes prominent features near the Hartebeest River, where it behaves much as inclined sedimentary rocks do, giving rise to short ranges with steep escarpments and less steep dip slopes where the foliation does not dip vertically or lie horizontally. The latter is a very unusual condition, though found in the central portion of the Drie Kop area, which has a dome-structure.

The limit between the Karroo and pre-Karroo rocks is rarely marked by any feature on the ground, and as the base of the former is a tillite of which the matrix disintegrates readily while the boulders and pebbles are on the whole very resistent, there is a fringe of boulder-covered ground in front of the limit of the formation.

The peculiar country known as the Bult, and in the eastern part as the Kaaien Bult, has no definite boundaries; though it includes the southern end of the hills made of the quartzites and schists of the Kaaien beds[1] where those hills begin to pass under the Karroo formation, it does not include the hills

[1]The name Kaaien was given to them in the Report for 1908 because many farmers in the country south of Brakbosch Poort, when asked what kaaien klip was, pointed to pieces of quartzite from those beds.

north of Doonies Pan. Its chief characteristics are its generally undulating surface, the lack of well-marked valleys and the abundance of small pans up to about 500 yards diameter. The pans are more abundant in the region of the Dwyka formation than further north, but it seems impossible to say where the Bult ends until one reaches either the Orange and Hartebeest Rivers, the high Kaaien hills, or the upper Dwyka shale country to the south, but the farms adjoining the rivers are not held to be on the Bult.

There can be no doubt that the general shape of the Bult just north of the Dwyka boundary is what it was when it was being buried under the Dwyka tillite. The further north one goes towards the Orange River, and towards the Hartebeest, this ancient land surface is more and more modified by the valleys draining into those rivers.

The surface of the tillite country is of the Bult type, but south of it, on the upper Dwyka shales, the surface is remarkably flat, and all the prominent features are due to the outcrops of dolerite sheets and dykes; still further south the Ecca beds form wide plains backed by escarpments of dolerite and the sandstones of the Beaufort series. The Beaufort beds and the dolerite together form a belt of high but deeply dissected country called the Karree Bergen, of which only a small portion has been examined.

The Orange River receives but little water directly from this area; the longest of the valleys opening directly into that river is only about 30 miles long. The Hartebeest River, which enters the Orange some 50 miles below Upington in a locality which has not yet been surveyed, drains the whole of the rest of the district.

Hartebeest is the name given to the conjoined Zak and Olifants Vlei Rivers, which together drain the districts of Kenhardt, Carnarvon, Fraserburg, Sutherland (except the Tanqua valley) and the eastern part of Calvinia, an area of over 30,000 square miles. The local streams which enter the Hartebeest below the confluence of the two large rivers are of little importance; the longest is Mottels River, which drains the country near Brakbosch Poort 50 miles from the Hartebeest, but there is rarely water in it.

Though the Hartebeest drains a large area, in fact it has the largest drainage basin of any river in the Colony after the Orange and Molopo, its bed is very small and remarkably free from boulders and pebbles. Going up stream from Vyf Beker, a farm about 18 miles below Kenhardt, to the junction of the Zak and Olifants Vlei Rivers, the bed becomes

on the whole narrower and confined between higher banks. Passing from the ancient rocks of Kenhardt on to the Dwyka tillite the continuity of the bed is lost, and it breaks up into a series of disconnected kolks, while the valley widens out very considerably; on the Upper Dwyka Shales the beds disappear altogether, and the valleys are great flats covered with alluvium and small bush without a river bed. In times of heavy rain the water in these valleys is shallow but in places as much as 6 miles wide. This remarkable flattening of the slope as one goes up stream from the ancient rocks on to the Karroo formation with its very slight southerly dip is due mainly to the relative hardness of the two groups of rock; the rivers have been able to erode their wide valleys in the upper soft formation, in which the almost horizontal position of the strata lends itself to the production of plains, much faster than they can cut down into the older and harder rocks of Kenhardt. The Orange River, the level of which governs the scope of downward cutting of the Hartebeest River, is well supplied with water from a very large region to the east, and in this district its bed is still over 2,000 feet above sea level; therefore it is cutting its bed down faster than the Hartebeest River can keep pace with, as the latter only runs occasionally, not even yearly.

Thus, in the course of the Hartebeest and its two large tributaries, there are two points of great importance in the regulation of the slope; one of these, the junction with the Orange, is being lowered comparatively rapidly; and the other, the boundary between the Karroo and the ancient formations, is being cut down comparatively slowly. The Hartebeest River, therefore, has a steep fall between these two points and the tributaries a very low fall above the outcrops of the ancient rocks. The best measurements of the fall available are those afforded by the contoured map prepared by the Intelligence Department of the War Office, though the sheets do not include the whole length of the rivers. Above the outcrop of the ancient rocks the fall is about one foot a mile, below that point about eight feet a mile.

Very little work was done on the Zak River, and beyond stating that a considerable deposition of alluvium is taking place on the flat bush-covered plain which the river floods occasionally, nothing can be said at present.

The tributaries of the Olifants Vlei River rise at the foot of, or behind, the Karree Bergen and the flood water spreads over great flats above Van Wyk's Vlei. Unfortunately this has been interfered with artificially, and in a number of places the rivers have cut deep channels in the alluvium and through

erosion are radically altering the face of the country. At Van Wyk's Vlei the waters divide, part going down to the south-west side of the sand dunes and part into the depression to the north-west which receives the drainage from the Bult. The valley of the Olifants Vlei River is choked by sand dunes down its centre, and between the sand hills the water makes its way till it spreads out once more at Koppies and narrows again near Verneuk Pan.

Between Van Wyk's Vlei and Boter Leegte there are similar surfaces over which the flood waters spread on their course to the great dam; but these surfaces support a growth of small karroo bushes except where the gradients are very low and then the surface is bare red clay with shale showing here and there. Part of the drainage from Dubblede Vlei travels to the north-east, the remainder finding its way into the large depression on Jagt Pan; when that overflows, the water escapes into a channel which broadens out at several points and after passing through a gap in the dolerite ridge at Riet Kops Kolk, spreads out over the lower end of Verneuk Pan. The tributaries of the Olifants Vlei River from a considerable area in Fraserburg and a small area in Carnarvon enter it by way of Verneuk Pan, which also receives part of the Olifants Vlei water. Verneuk Pan is a flat tract of country, about 17 miles long by 6 wide, made of sandy mud with numerous patches of shale and fibrous limestone outcrops nearly at the level of the mud; the mud bears no vegetation, but a small green succulent plant grows on the outcrops. Probably no part of the pan lies below the level of the dolerite outcrop which appears at places through the mud at the exit; over this sill run part of the Olifants Vlei River and any other water that leaves Verneuk Pan. Thus Verneuk Pan is not a depression but a wide flat valley floor cut in soft strata behind a bar of hard rock, and covered incompletely with sandy mud which will not support plant growth.

On a small scale it resembles what happens in the Zak and Olifants Vlei Rivers when they approach the hard rocks of Kenhardt—the valleys expand enormously in the soft shale area. Unlike those valleys, however, Verneuk Pan has little alluvium on its surface. A prospecting pit or well in the middle of the eastern part of the pan exposed three inches of sandy mud containing small crystals of gypsum and lying on a layer of gypsum one quarter of an inch thick, below this are horizontal shales and thin fibrous limestones (Upper Dwyka shales). The shales were found at several places at depths of less than four inches on the floor of the pan, and over a wide area traces of the joints in the underlying

rock are visible on the mud of the pan owing to its darker tint above the joints when damp, and the slight deposit of salt along the same lines when dry. Thus the pan is an almost flat surface cut in the soft Upper Dwyka shale.

The absence of vegetation from the mud floor is probably due to the brakness of the soil, though the patches of salt actually seen on the surface were small and very thin.

Verneuk Pan is the largest example in this area of a large flat surface almost devoid of vegetation lying in the course of a valley, but there are numerous smaller ones along the Hartogs Kloof Valley, the Zwart Kop valley and that of the river going northwards from Dubblede Vlei ; though they are not found in the Zak or Olifants Vlei valleys. This difference seems to be due to the fact that the large Zak and Olifants Vlei valleys are more frequently flooded, and consequently more frequently have parts of the salt removed, than is the case with the shorter valleys, in which the salt accumulates in consequence of the slope being so very slight above the hard bars that are a primary condition for the cutting of the wide plains on the soft shale. The absence of vegetation in its turn allows the wind to scour the mud flats, and in course of time great quantities of dust and sand must be removed from them in this way, whereas in the bush covered flats of the Zak and Olifants Vlei valleys the wind can do little work of this nature. Whether the dust and sand exert any appreciable erosive action on the low outcrops which are gradually laid bare by the removal of the mud is doubtful, for an examination of very many of these outcrops in Verneuk Pan failed to reveal the characteristic fine scratches and polish due to wind-blown sand. The outcrops are of soft, easily disintegrated rocks, which probably break up under the diurnal changes of temperature, and thus afford material for the wind to remove, too fast to retain traces of the sand blast.

It is unfortunate that this type of feature developed on the soft shales in the course of a valley has received the same name as the depressions in areas of internal drainage such as Kuie Pan and others, but it is the case, though some of the depressions themselves are called vleis, *e.g.*, Haakschein Vlei in Gordonia.

It is possible that under favourable climatic conditions lasting for a long period a flat surface, such as Verneuk Pan seems to be, may lose so much material that it becomes a depression. A very accurate series of levels would have to be made to find out the actual shape of the Verneuk Pan floor at the present time, but it does not contain any depression below the level of the dolerite lip at the exit.

The silting up of such a depression would be prevented so long as the water entering it provided enough salt to hinder the growth of plants, and so long as the depression remained shallow enough to allow the wind to remove dust from it.

## THE KHEIS SERIES.

In the Annual Report for 1908 the term Kheis series was enlarged so as to include the Marydale beds, and the quartzites and quartz-schists of the Brakbosch Poort hills, etc., were considered to form the upper and thickest sub-division of the series, under the name of Kaaien beds. That the Marydale beds are the older of the two could not be proved, but from the relations of the two groups to the granite and gneiss it was supposed that the Marydale beds are the older.

The field-work in 1909 included the examination of the Wilgenhout Drift beds[1] lying in the Kenhardt division, and though they are here quite as much disturbed as across the Orange River in Gordonia, there are three localities where their relation to the Kaaien beds is laid bare. At two of these—on Karos, and the Wilgenhout Drift–Stofgat boundary—there is a marked parallelism between the dip of the two series, and both follow the same curving trend. At the third locality, also on Karos, there is also a parallelism between their strike, but the boundary is nearly straight. At a fourth locality, on Stofgat, the junction is complicated by a fault and by sharp contortions in the Wilgenhout Drift beds. The most suggestive evidence is found on Karos, where the main south-western branch of the Brakbosch Poort hills ends within about a mile of the Orange River. The quartzites and schists of these hills there dip north-east, under the Wilgenhout Drift beds and gradually turn round through north and north-west to south-west, dipping under the Wilgenhout Drift beds along a boundary line about five miles in length before the junction becomes obscured by later deposits, the Koras series on the north-east and red sand on the south-west flank of the mountain. The general arrangement of the beds in this locality is clearly that of an anticline with its axis inclined towards the north-west, and the details of the succession show that there is probably a conformable passage from the Kaaien beds upwards into the Wilgenhout Drift beds. The evidence for the conformity is that below the uppermost quartzite band of the Kaaien beds there is a thickness of about 20 feet of silky micaceous phyllite and below this again a thick quartzite. These three rocks can easily be followed

---

1 Ann. Rep. Geol. Com. for 1907, pp. 35-42.

almost continuously round the point of the mountain, where their continuity over the axis has been partly broken by denudation. Above the highest quartzite there is sheared green slate and lava, often reduced to the condition of a slate, but retaining lenticles of less sheared volcanic rock. There is also a band of limestone and calcareous slate, about 10 feet thick and with a rusty yellow weathered surface, lying about 250 or 300 feet above the base of the Wilgenhout Drift beds round the quartzite outcrops. A very similar but thicker limestone was again found near the base of the Wilgenhout Drift beds on Wilgenhout Drift. These facts all confirm the supposition that there is a conformable passage between the two groups.

When dealing with the stratigraphical relations of groups of beds strongly affected by earth-movements it is obvious that the order of succession adopted should be that observed in the least disturbed portions of the region, and therefore the Wilgenhout Drift beds will be placed in the Kheis series as the uppermost member of that series, although, as will be described presently, there are places where the actual succession is inverted.

The question arises whether the Wilgenhout Drift beds are really distinct from the Marydale or whether the two groups are identical, the differences between them being due to the greater extent to which the Marydale beds have been metamorphosed. There is a general resemblance in the characters of the two groups, for each includes basic and acid lavas, and various kinds of sediments, including limestone and siliceous rocks containing much magnetite, but there is no close similarity between the order of succession. The Wilgenhout Drift beds are very much thicker than the Marydale, though this fact might be explained both by an original difference in this respect between the deposits over a wide area and by the thinning of the more highly metamorphosed part. There is nothing known in the Wilgenhout Drift beds corresponding to the thick arkose at the base of the Marydale beds on Welgevonden and Zoet Vlei in Prieska,[1] but this difference might be explained on the assumption that the base of the former group has not been seen, and that the area occupied by the beds along the Orange River is of an anticlinal and not synclinal type as it appears to be. Little weight, however, can be attached to lithological differences between rock groups so far apart of which the general structure is not established. An attempt to make out the exact structure

1 Ann. Rep. Geol. Com. for 1908 p. 19.

of the area occupied by the whole series in Prieska and Kenhardt has not been made. Such an attempt would take a long time and would be very difficult on account of the want of distinguishing characters in various parts of the thick Kaaien group. The important points at present known are, first the apparently synclinal structure of the Kaaien and Marydale beds on Stuurman's Puts in Prieska, where the latter wrap round the former[1] and are surrounded on three sides by granitic gneiss; secondly, the occurrence of the Marydale beds along the north-eastern flank of the hills north of Stuurman's Puts, with gneiss to the north-east; thirdly, the occurrence of isolated bands of the Marydale beds in the Prieska granite area; and finally, the anticlinal character of the north-west end of the main range of hills on Karos. Thus the Marydale beds are closely associated with the gneiss along the apparent base of the Kheis series, while the Wilgenhout Drift beds are only known to be penetrated by three masses of gneiss, on Stofgat and Karos, and these are of comparatively small size, the largest measuring three miles by less than one and a half. This circumstance tends to corroborate the view that the Marydale beds form the lowest member of the series and the Wilgenhout Drift beds the highest.

On the assumption that the Brakbosch Poort range has the general structure of a syncline the Marydale beds should be found along the south-west flank of the hills, but there is no band of schists and basic granulites at the immediate foot of the hills where the western limit of the quartzite is visible. This junction is concealed by sand at many places, but it can be seen on Klip Pan (Put Zonder Water), Brakbosch Poort and a few other farms, where gneiss either lies in contact with the quartzites or a pale granulite intervenes between them. At various distances from this important boundary line metamorphic rocks of different kinds occur in the gneiss of Kenhardt. Many of these are similar to rocks in the Marydale beds of Prieska, but others—*e.g.*, the limestones and calc-silicate rocks of Nrougas and Dwaal Geesi—show new minerals developed on a more extensive scale than in the Marydale limestones of Prieska. These very varied rocks are in some cases obviously of sedimentary or volcanic origin, but it is impossible to write a systematic account of them based on stratigraphical position. They occur in strips or irregularly-shaped masses surrounded, and often penetrated, by gneiss, and can be placed in the Marydale group on account of their resemblance in petrological characters to rocks included in that group.

1 Ann. Rep. Geol. Com. for 1908, p. 33.

### *The Marydale Beds.*

The various rocks placed in this group will be described according to their localities. The chief types are hornblende and pyroxene schists and granulites, quartzites and felspathic rocks showing distinctly detrital fragments, various phyllites and mica-schists and quartz-schists, schistose rocks derived from acid lavas, and a considerable variety of metamorphosed limestones.

The general form of the strips and masses of Marydale beds in Kenhardt is that of elongated lenticles surrounded on all sides by granite or gneiss. Rounded masses are unusual, and there seem to be no rectangular masses. The strike of the Kaaien beds of the Brakbosch Poort range and the associated hills further north is usually between N.10° W. and N.N.W., and the beds have westerly dips. The strike of the beds assigned to the Marydale group in Kenhardt changes from N. 10° W. in the eastern part of the division to N.W. and W.N.W. the further west one goes, though there are many exceptions due to the existence of irregularly-disposed folds. In the largest continuous mass of these beds, that which extends from the middle of Klein Begin across Hartebeest Vlakte to Trooilaps Pan, a distance of over 15 miles, the change increases regularly northwards.

At the north end of the hills made of the Kaaien beds, where they are cut off by the Orange River, no large band of schists was met with in the few miles of country examined on the west side of the hills. On the hard ground just south of the alluvium near the main road drift, on Olyvenhout Drift, there are some small streaks and masses of mica-schist and epidotic quartzite enclosed in the gneiss. The mica-schist is seen on the rise on which the Round House stands, and is just like the mica-schist veined by granite exposed on the approach to the drift on the Upington side of the river. There are many thin bands of pale and dark granulitic rocks in this neighbourhood; they are somewhat contorted together with the bands of more or less foliated muscovite-biotite gneiss which separate them, and large veins of a coarse pegmatite containing garnets and magnetite traverse both granulite and gneiss. Near the drift the foliation of the gneiss and the strike of the granulites is usually about N.N.W., but further south both foliation planes and the thin bands of hornblende schist seen near the main road have W.N.W. or even E.–W. strikes with southerly dip.

Further south, and about two miles N.E. of the middle west beacon of Olyvenhout Drift, there is a curved ridge with

a beacon on it. The ridge (see fig. 1) is chiefly made of a strongly foliated rock with dark "eyes." Under the microscope this rock (2414) is seen to have a ground mass of grains of a colourless monoclinic pyroxene and a small amount of actinolite, either in separate grains or grown on to the pyroxene, sphene and patches of sericite flakes with a colourless mineral, probably a felspar, and epidote ; the eyes are patches

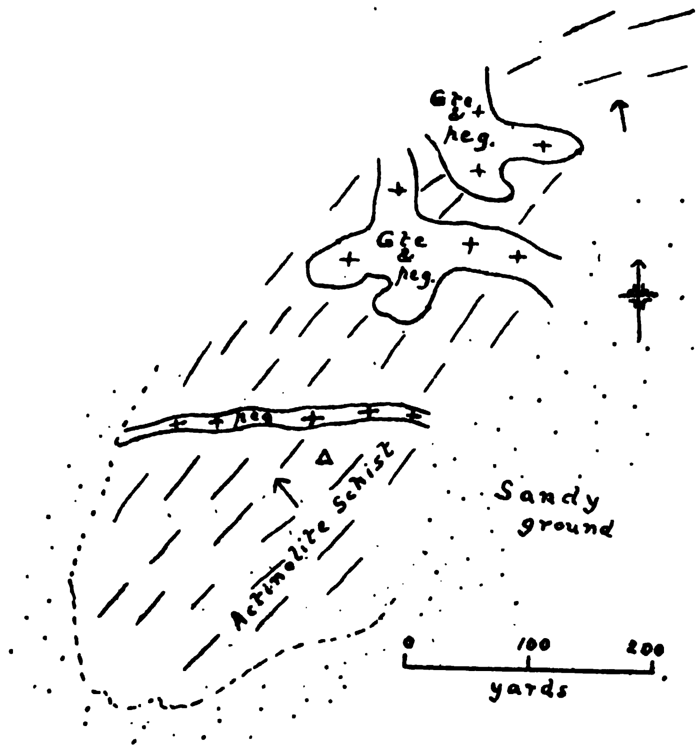



FIG. 1.—Plan of actinolite-schist and granitic outcrops on Olyvenhout Drift

of actinolite grains with a few pyroxene and sphene grains, or larger masses of actinolite intergrown with the pyroxene and enclosing variously disposed actinolites. This type of actinolite schist was not met with elsewhere in the district and its origin is uncertain, though it was almost certainly an igneous rock on account of its mineral composition. It is traversed by coarse granite and pegmatite, the latter being

1 Ann. Rep. Geol. Com. for 1907, p. 22.

one of those, so frequently seen in Kenhardt, which consist largely of microcline in irregularly bounded crystals of great size, so that cleavage faces over a square foot in area can be obtained.

On the north-western part of Ratel Draai and the neighbouring portions of Olyvenhout Drift and Bethesda a large amount of quartz-and mica-schist are seen, though they are so riddled with granitic gneiss and pegmatite, and the ground is so obscured by sand and small patches of surface limestone, that the delimitation of the schists and granitic rocks would take too long a time to be practicable now. Associated with the mica-schist in this area are a few thin bands of a curious whitish-grey rock with pink and green spots. It breaks like a quartzite and lies parallel to the foliation of the schists. In thin sections (2410–1) its texture is seen to be granulitic and its constituents plagioclase, quartz, colourless augite and a little actinolite, the former in large irregular masses enclosing grains of the other minerals poikilitically, pale pink garnet both in irregularly bounded poikilitic masses and small crystals bounded by faces, sphene, and a very little magnetite. A rock similar in all respects to this peculiar granulite was seen on Kalk Gat (a part of Ratel Draai) rather over two miles west of the beacon common to Ratel Draai, Trooilaps Pan, Klip Bakken and Hartebeest Vlakte. A thin section (2434) shows that this rock is made of the same minerals as the other and has the same texture, but the plagioclase in the Kalk Gat rock is less affected by straining than that in the other; it has the extinction angles of andesine. The Kalk Gat rock is associated with several varieties of grey granulites, darker hornblendic granulites and mica-schist with innumerable parallel bands of gneiss, and irregularly disposed veins of pegmatitic granite. The general strike of these granulites and schists lies between N.W. and W.N.W., and they form one belt with those described above. On the north-east side they are flanked for about five miles by a band of dark hornblende-schists and granulites, though a belt of granitic gneiss of varying width lies between them. The dark rocks give rise to a line of prominent ridges and hills, on one of which the beacon common to the four farms stands. The belt of dark rocks, including intercalated grey granulites and bands of gneiss and pegmatite, which together may make up about a quarter of it, is about 500 yards wide. The chief rock in the belt is a rather coarse hornblende-schist with elongated patches of pale aggregates looking like drawn out amygdales. In thin section (2432) a specimen of this rock shows streaks and grains of a strongly pleochroic green hornblende set in a con-

fused mixture of sericite, epidote, plagioclase and sphene, with tremolite and calcite in addition in parts ; the pale patches are of felspar grains with lower refraction than the balsam at the edge of the section and the characteristic cross-hatching of microcline. A few grains of this microcline occur outside the large clear patches but in their immediate neighbourhood, but they are not seen in the rest of the slice. There seems to be no free quartz. Some of the pale schistose and granulitic rock in this belt is amygdaloidal. A section from a slightly schistose specimen (2433) consists of grains of green pleochroic hornblende, similar to that in the dark schist but less in quantity, actinolite (no tremolite was seen), a very pale green augite in occasionally large masses, microcline, sphene, and a little calcite and biotite ; the supposed amygdales consist chiefly of microcline, sometimes with much epidote, generally with a little actinolite and calcite ; in one case quartz is certainly present.

At Blauwbosch Dam, between the beacon ridge just described and Olyvenhout Drift, the belt of schistose rocks was again traversed ; the hornblende rocks were not seen here, but mica-schist occurs in belts which are not traceable for distances over a mile ; the well below the dam is sunk on one of the mica-schist layers, and a second thick one lies between this well and the north corner beacon of the farm. There are many thin layers of mica-schist not more than 10 feet thick, but the greater part of the rocks in the position of the schist-belt are gneiss and pegmatite. A peculiar rock, very different from the gneiss but of doubtful origin, is situated on the boundary of Trooilaps Pan and Blauwbosch Dam and lies in this schist belt. It is a dark rock which weathers with a reddish black banded surface ; in places the bands are contorted, sometimes they are scarcely discernable. In thin section (2440–1) the constituents are seen to be plagioclase felspar, quartz , biotite, magnetite, green spinel, apatite, sillimanite and a colourless positive biaxial and probably monoclinic mineral with rather high refraction but very low birefringence, which may be chloritoid. In one of the specimens the quartz is much more abundant in some layers than in others, and the biotite is almost confined to one layer ; in the other specimen the arrangement is quite irregular generally, with patches rich in sillimanite or biotite and iron ore. The texture is schistose rather than granulitic. This rock forms an area about two miles long and some 400 yards wide, but there are bands of grey granulite in it.

Towards the south-east this belt of schists and granulite becomes less definite ; so much granitic gneiss comes in that

it can no longer be distinguished from the surrounding rock on Zand Ruggens.

On the large farm called Vaal Kopjes, which extends nearly 13 miles southwards from the river just above Upington, there are several long ranges made of quartzites and quartz-schists which are placed in the Kaaien group on account of their character; they do not reach Trooilaps Pan, though another small ridge of similar rocks does so, and in the eastern part of that farm several other such ridges project through the thick covering of blown sand which lies west of the main range of the Kaaien beds. No definite schist or granulite bands of large size referable to the Marydale beds were found on Vaal Kopjes, though there are peculiar cordierite granites and other rocks which are not normal igneous rocks but which probably owe their peculiarities to material derived from sediments. Some fine grained granulites are seen at places and they become more abundant near the Trooilaps Pan boundary. They have the mineral composition of granite and are traversed by massive pink and grey granite, and the whole mass at one locality ends off abruptly against coarse "flaser"-gneiss.

On Trooilaps Pan there is an important mass of quartzites, slaty rocks, hornblende-schists and granulites with a small proportion of gneiss in thin bands parallel to the strike and foliation. The general strike is E.S.E. and the length over eight miles, but at the east end it passes under red sand, so that the relation to the quartzites with N.N.W. strike further east cannot be ascertained. The belt is rather under two miles wide near the homestead (called Sand Puts) but thins out and ends indefinitely in gneiss to the W.N.W. The quartzites often contain garnet, and the grey granulites are also garnetiferous. The slaty rocks are not well exposed; they are soft phyllites and weather more rapidly than the hornblendic rocks. A rather remarkable and finely-banded rock is quarried for building purposes near Sand Puts. It has a dark greenish colour streaked with white or pale grey lenticular layers; the dark bands are schistose owing to the parallel arrangement of the hornblende, but the pale layers have a granulitic structure. In thin section (2439) the dark layers are seen to be made chiefly of a strongly pleochroic yellow-green irregularly-bounded hornblende arranged with the long axes parallel and a little plagioclase in grains (andesine), apatite and epidote; two pale bands in the section consist of very pale green augite in large anhedral grains, plagioclase, sericite flakes, epidote, a little green hornblende and some calcite and sphene; one thin band consists of green hornblende, microcline and zoisite. A second and smaller

belt of dark granulitic rock with garnets lies to the south-west of the large one, and several small belts of phyllite and quartzite occur on the southern part of the farm.

One of the quartzite belts, which is only about 100 yards wide on this farm, is continued south-eastwards through Hartebeest Vlakte on to Klein Begin. The strike turns more and more to the south as the belt is followed southwards, and new kinds of rock come in, first mica-schists, then grits and conglomerates on the north-east side, and a great thickness of phyllites and mica-schists on the south-west side of the belt on Klein Begin. Intrusions of gneiss occur at various places in the belt, thin bands of gneiss lying parallel to the foliation of the schists; on Klein Begin the belt terminates indefinitely owing to an increase in the number of these gneiss bands. There is a southward projecting tongue of gneiss on Hartebeest Vlakte which nearly separates the belt into two parts. The chief point of interest in this belt is the presence of the clearly detrital grits and conglomerates on Hartebeest Vlakte. No hornblende schists were seen in it, nor were any typical granulites seen, to which the grits present a rather close resemblance in the field and in hand-specimens. Pebbles of quartz, granite and a fine grained black rock lie in a gritty mixture of quartz and felspar grains cemented together by a recrystallised ground mass. In thin section (2436) the detrital origin of the quartz and felspar fragments is clear; the felspar is chiefly plagioclase, microcline is not visible ; the quartz fragments lose their identity more readily through granulation than the felspars, which are in a few cases fringed with a fine-grained mosaic evidently derived from the grains themselves. A few large muscovite flakes, considerably bent and frayed at the ends, are probably original constituents, and so also are some apatite grains. The interstitial matter consists of quartz, felspar, muscovite and biotite; the biotite has evidently been developed in place, it is greenish-brown in colour and fits in amongst the new quartz and felspar in a way that detrital flakes could not do; there are some minute flakes of muscovite of uncertain origin. A slice (2437) from another specimen shows a finer grained rock with more matrix than the last. The characters are in general the same, but there is much of a greenish micaceous mineral in very small flakes in the matrix and penetrating the grains of quartz and felspar.

These obviously sedimentary beds occupy a belt about 400 yards wide, for the most part separated from the larger belt to the west by granitic gneiss but joining up with it at the south-west end. Only a small amount of grit and conglomerate was seen in the larger belt, most of which is made

of quartzite and phyllites. These rocks crop out occasionally on flat ground, and there is no appreciable distinction in character between the gneiss areas and the sedimentary rocks over a large part of the belt, though between Petrus Rust and Klein Begin the phyllites and quartzites form a low bult. The dip throughout the belt fluctuates near the vertical.

The rocks on Hartebeest Vlakte are the only ones with any close resemblance to the arkose of Zoet Vley in Prieska[1] yet found in the Kenhardt district; the grits enclosed by gneiss on Piet Rooi's Puts are not highly felspathic, for felspar only occurs in the matrix of that rock.

A broad area of coarse granite and granulitic gneiss separates these sedimentary rocks from a quartzite and quartz-schist belt which extends for 14 miles through Hartebeest Vlakte and Klein Begin. Several hills and ridges rise from this belt, the most prominent being called Vaal Kop, a hill rising between 400 and 500 feet above the flats. Granite and gneiss separate this belt from a smaller but similar one to the north-east, but on Klein Begin the red sand reaches it, and only isolated patches of gneiss, quartzite and actinolite rock are seen between it and the main range of the Kaaien beds. All these quartzites and quartz-schists resemble those of the Kaaien beds closely and may be assigned to that group. The actinolite rock is only occasionally schistose; it is generally a tough, massive rock in which the actinolite lies in all directions, but it is accompanied by bands of a mottled grey rock striking N.N.W. Both these rocks are traversed by dykes of a rather fine-grained grey biotite-granite running W. 11° N. The amphibolite is seen in thin section (2405) to consist of actinolite and a little plagioclase in grains wedged in between the actinolite or enclosed by individuals of that mineral. The mottled rock consists of irregular grains of a colourless monoclinic pyroxene, the smaller of which are often enclosed by calcite, a little green spinel and some zoisite, and an undetermined positive biaxial colourless mineral with low refractive index and moderate birefringence. This rock (slice 2406) presents a decided resemblance to certain rocks found further west in the district which are metamorphosed limestones, but whether it also was an impure limestone is not clear, and the accompanying amphibolite is of uncertain origin.

South-south-east of Klein Begin house there is a mass of quartzites, quartz-schist, grey banded quartzite and a little hornblende-schist forming a U-shaped area about four miles

1 Ann. Rep. Geol. Com. for 1908, p. 20.

long, with the open end pointing S. 10° E. on Boks Puts. Excepting two miles of the north-east boundary, where sand reaches it, granite and gneiss are in contact with the altered sediments. This mass may be regarded as a part of the Kaaien group, and the hornblende-schist in it resembles the dykes of that rock in the Kaaien beds further east.

No outcrops that can be classed with the Marydale beds were seen on Koegrabe or on the central and eastern part of Zonder Pan. A large body of such rocks stretches from the middle of Rooi Puts in an E.S.E. direction through the corners of Zonder Pan and Jacomyn's' Pan to Hartebeest Pan, a distance of nearly 14 miles. It forms a low bult, and is partly covered on the east by an outlier of Dwyka tillite. The chief rock in this mass is a coarse phyllite or greywacke with much mica, quartz, and apparently felspar, but it is deeply weathered and the outcrops are poor. In parts the rock becomes more quartzitic. Hornblende-schist is occasionally recognisable on the bult, and intercalations of granulitic gneiss are frequent, though typical gneiss was only found at the extreme north-west end and near the east end. There are bands of fine grained dark rock impossible to determine in the field without previous experience of their microscopic characters. A tough schistose rock on Jacomyn's Pan (2342) is seen, under the microscope, to consist of small blue-green hornblendes, which tend to collect in indefinitely bounded patches, epidote, zoisite, and a little quartz and calcite ; small veins of granular quartz and epidote traverse the slice. A specimen from a compact dark grey rock, with an obscure parallel structure visible on the outcrop, proves to be a very fine grained hornblende-schist made of strongly pleochroic hornblende with occasional prism faces lying in a fine grained quartz-plagioclase mosaic with some magnetite, epidote and small flakes of brown mica. The plagioclase occasionally occurs in large patches broken up by bands of the mosaic and enclosing small hornblendes, magnetite, epidote and mica. This specimen came from Jacomyn's Pan, but similar looking rocks are of widespread occurrence in this mass of schists. At the north-west end a broad wedge of gneiss separates two projecting tongues of quartzite, and the latter are further split up by narrow layers of gneiss. Veins of a dark coloured bluish quartz are frequent on this bult ; they are rather short but thick, and as a rule appear to lie parallel to the strike of the rocks, though some of them run irregularly across the strike.

On Kawida (southern part of Zonder Pan) there is a mass

of chlorite-schist penetrated by gneiss. To the south-east of this patch of schist there is an elongated patch, about four miles long by one wide, of quartzite, a banded felsite with lenticular streaks of quartz, tough blue-grey hornblendic rocks which merge into cleaved or thinly foliated rocks of similar type, and peculiar granulites. All these varieties strike in one direction, nearly N.W., and have a vertical or nearly vertical dip. A section from one of the felsitic rocks (2345) shows a very fine grained mosaic of quartz and felspar with minute flakes of both greenish-brown mica and sericite; the lenticles are a coarse quartz mosaic with very little mica. This rock was probably an amygdaloidal acid lava; it forms thick bands separated by the dark massive or finely foliated hornblendic rocks. A section from a massive outcrop of the latter (2346) consists of patches and ill-defined layers of actinolite in a confused aggregate of epidote and zoisite with a little chlorite, magnetite and sphene. The actinolite has a partially parallel arrangement, but the epidotic aggregates evidently interfere with the schistosity. A slice from a bluish rock with small pale patches (2347) shows a somewhat banded granulitic mixture of labradorite, hornblende, augite and epidote. Labradorite is the most abundant mineral, but certain bands or irregular lenticles are rich in a brownish-green hornblende or colourless augite, rarely a mixture of the two. Most of the grains have the typical granulitic shape, but some of the hornblendes have ragged ends.

Another large area containing much banded felsitic rock and also much grey granulite lies on the boundary between Put Zonder Water and Hartebeest Pan, and small streaks of felsite are found embedded in gneiss in this region.

Three small patches of quartzite were found in the gneiss of Put Zonder Water.

About a mile W. 40° N. of the house on Put Zonder Water there is a peculiar mixture of metamorphic rocks and granulitic gneiss. The chief metamorphic rock is a whitish one with patches of a pale green pyroxene, but it merges into a mottled grey and green variety quite irregularly. Two slices (2327 and 2348) from these show that they are made of almost the same minerals, but green spinel is abundant in the darker variety. The monoclinic pyroxene is colourless in thin section and occurs both in large masses enclosing green spinel and in grains; it does not show crystal faces; epidote and calcite are present in fair quantity, also two minerals of uncertain identity; one of these may be zoisite, but the other is a uniaxial mineral with moderate refractive index and low negative double refraction, and may be gehlenite. These

rocks form a mass about 700 yards long by 200 wide, and they terminate indefinitely in a coarse granitic gneiss at both ends; irregular veins and masses of a pale rock without quartz occur within the pyroxenic mass. A thin section (2329) from one of these veins has a granitic texture grading into the granulitic; the constituents are actinolitic hornblende in large but irregularly bounded prisms enclosing grains of felspar, and grains of plagioclase (andesine) with a little sphene. A slice (2326) from another vein is almost entirely made of the same kind of plagioclase with a little calcite, zoisite and chlorite. This mass of pale rock is flanked on either side by quartzite, quartz-porphyry and gneiss; the quartzite forms discontinuous bands up to 20 yards wide, and on the south-west side a thin band of coarse hornblende-schist was traced at intervals on the inner side of the quartzite belt for 300 yards. A thin section of this schist (2328) shows that the hornblende is a strongly pleochroic blue-green variety, often grading into a paler kind, forming irregular prisms which enclose strained quartz grains; interstitial patches are made of zoisite, sericitic mica and magnetite.

On Jacomyn's Pan there is a mass of fine grained grey granulite with slight banding stretching north-west in the gneiss and granite, which are markedly garnetiferous in this neighbourhood. The granulite belt is nearly five miles long and 400 yards wide. There seems to be a complete break between it and the larger granulite belt on Rooi Puts, though as the intervening ground is a wide laagte with much sand there may be a concealed connection.

The Rooi Puts belt is surrounded by granitic gneiss, but in the latter there are small bands of schists which are decomposed to a considerable depth and therefore are not often found in outcrops. Two wells on Lower Rooi Puts have been sunk on such soft bands. The rock from one of them is a gneiss with garnets and much mica; from the second was obtained a grey schistose rock (2338) made of quartz, biotite, sillimanite, magnetite, zircon and a little felspar. The quartz is granulated at the contact of the grains; the biotite is a strongly pleochroic reddish brown variety and is very abundant, with it is associated sillimanite in slender prisms, but the fibrous condition is not seen; the felspar is albite, but occurs in small quantity only. Some garnetiferous rocks in the granulite prove to be similar in mineral composition to some of the gneisses, though they differ considerably in appearance from the usual gneiss. A thin section of one of them (2337) shows a granulitic mixture of quartz, albite, red-brown biotite and chlorite, garnet and magnetite. The

garnet is pink and forms large irregularly shaped grains enclosing the other constituents.

Much of the rock in this belt weathers with a peculiar dark polished surface and has a reddish colour on a fresh surface owing to the presence of garnet, but the other constituents are not discernable ; similar looking rocks prove to have very different compositions. A slice (2339) from an outcrop near the conspicuous white quartz kop E.N.E. of Lower Rooi Puts is made of a medium grained granulitic mixture of labradorite, or a more calcic variety of felspar, in large amount, brown hornblende, almost colourless enstatite with rows of rod- or plate-like opaque inclusions cutting the cleavage planes at various angles though each inclusion lies parallel to a cleavage plane, and magnetite. Both the hornblende and enstatite frequently enclose small grains of each other as well as of felspar and magnetite. A dark rock from Upper Rooi Puts, in the same belt, is made of quartz, cordierite, garnet, staurolite, sillimanite, biotite and magnetite. Cordierite is present in considerable quantity and is often twinned, occasionally so that the grain is divided up into six segments each traversed by other twin planes ; it forms a curious intergrowth with quartz, and with this intergrowth is associated the fibrous form of sillimanite not seen elsewhere in the slice, although slender prisms of sillimanite are abundant ; staurolite is abundant and so is garnet, which is pink in thin section and encloses quartz and magnetite. Biotite is not abundant, and is in places altered to chlorite ; the cordierite shows only slight alteration to a yellow non-pleochroic material.

Though quartzites and other rocks of obviously sedimentary origin were not found in this belt there is little doubt that the rock last described represents one.

To the east of this belt and about half way between it and the large belt described on a previous page (see p. 25) there are a few outcrops of a platy porphyritic rock which presents peculiar characters ; it is a fine grained grey rock with rounded crystals of quartz and felspar, the platy structure is due to the arrangement of the minute micas in planes parallel to the foliation planes of the surrounding gneiss. Under the microscope (2340) the bulk of the rock is seen to consist of a very fine grained mosaic of quartz with brown mica flakes and tourmaline, no felspar was detected in this mosaic, but some blue hornblende is present in larger sized grains than the quartz and mica ; in two cases the hornblende seems to be a remnant of crystals which became granulated in their outer zones. In this matrix lie small crystals of zircon and apatite as well as large rounded felspars ; quartz crystals are

not seen in the slice. The felspars are remarkably clear, though they enclose very minute mica flakes and rutile needles. Some of the felspars are untwinned, others are repeatedly twinned and are probably albite. The outer zone of some of the felspars is granulated. This rock is apparently a metamorphosed porphyry, but whether it is a lava or intrusion is uncertain.

South of the rocks just described there is a wide area in which only quite small masses of schist were seen in the gneiss and granite. The only outcrops worth mentioning occur at Kombaers Brand, where a dark granulite with obscure banding on weathered surfaces and occasional bands of altered amygdales forms the top of a rise north of the laagte. The granulite is traversed by veins of porphyritic granite with slight gneissic structure, and graphic granite. The size of the granulite area is about half a mile in the direction of the rough banding (N.N.W.) and 300 yards at right angles to it; the boundaries are not exposed, but granitic gneiss surrounds the granulite. A thin slice (2332) from the latter shows a granulitic mixture of pale greenish-brown hornblende and labradorite, with very little sphene, apatite, pyrites and magnetite; biotite is visible in the hand-specimen. From a well sunk 200 yards away from the outcrops most of the rock thrown out is porphyritic gneiss, but in addition there are masses of a compact grey rock still adhering to the gneiss; they seem to be rather small inclusions in the gneiss and not parts of a dyke or other large mass. Under the microscope the grey rock (2334) proved to be a labradorite-enstatite-augite-hornblende-biotite-granulite; the hornblende is a pale brownish green variety and occurs round the enstatite and augite grains; the biotite is a peculiar orange-red variety and is strongly pleochroic; some magnetite and ilmenite with leucoxene round it, are also present.

West of Kombaers Brand the first rocks met with other than gneiss, etc., are green quartzites which form a thin band traced for about two miles along the strike on Steyn's Puts. In thin section (2335) the quartzite is seen to be made entirely of quartz and yellow epidote, the latter often in small crystals enclosed by quartz. The bedding planes are visible in this rock and dip at about 40° E.N.E. The thickness of the exposed rock is some 500 feet. There is a layer of breccia three inches thick in the quartzite, but its origin is doubtful, as the fragments are very like the rest of the rock. The quartzite is surrounded by sandy ground and alluvium, but

there seems to be no other rock between it and the gneiss on each side.

An inlier of hornblende-granulite with a small mass of granite and pegmatite projects through the Dwyka tillite on Klaar Praat. The granulite (2291) consists of green hornblende in poikilitic grains enclosing quartz, felspar and magnetite; the felspar is probably andesine; quartz is present in fair amount; magnetite and rather deeply coloured epidote are the remaining constituents.

In the valley of the Hartebeest River schists are first met with on Kruis Zuid, where thin bands of hornblende granulite and schist can be traced for considerable distances through the gneiss. These bands and the dip of the foliæ of the gneiss make a great curve round a centre on Koker Berg. Between two of the granulite bands on the south-west part of Modder Gat there is a thin layer of sheared quartz-porphyry with slaty matrix.

On Modder Gat and Zout River a central mass of coarse granulitic gneiss is surrounded by a wide belt of various granulitic rocks which form a uniform mass uninterrupted by bands of gneiss or granite on the north and west sides, but which are split up into three or four distinct bands on the south, and on the west are represented by only one thin band. Specimens taken from the thick northern part of the encircling belt have various compositions. One (2301) is made chiefly of andesine with little quartz and magnetite; sericitic mica is developed in some of the felspar grains. Another specimen (2302) contains much deep green hornblende and some epidote, sphene and garnet in addition to the minerals mentioned above; the epidote tends to wrap round the iron ore; the garnet has a reddish orange colour in thin section and does not show crystal faces. A third specimen (2303) has very little hornblende but much garnet in patches enclosing quartz and felspar, and a fair amount of bright yellow epidote, occasionally with an outer zone of less highly coloured epidote. A slice taken from the western band (2304) shows similar characters but an increased amount of the coloured garnet and very little epidote, hornblende and magnetite. The felspar in this rock is more altered than usual; the sericitic mica replaces felspar substance, and the flakes within one felspar grain behave as though they were parts of one crystal, giving the resulting mixture of felspar and mica the appearance of an intergrowth. A specimen (2293) from the southern part, where the belt is broken up by gneiss bands, shows little

quartz and hornblende, but much andesine and less garnet and epidote. Another part of the southern rock, taken from one of the thin granulite bands in continuity with the thick eastern portion of the belt but projecting into the gneiss, is a more basic rock than any of those just described. The slice (2294) shows no quartz but consists of a basic plagioclase (perhaps bytownite), blue-green augite, highly coloured epidote and garnet, and magnetite and sphene.

A peculiar feature in some of the fine grained white or grey granulites of Zout River is the presence of patches and lenticles of magnetite free from inclusions. No other constituent of the rock reaches the size of these patches, which are often over half an inch in diameter, while the other minerals are in grains less than one-twentieth of an inch wide.

On the outer side of this belt a second band of granulites frequently showing amygdaloidal structure was traced for 15 miles. In composition the rocks vary considerably, from grey granulites which are probably made of felspars, biotite and quartz, to a felspar-augite rock. A specimen (2305) from the western part of the band on Modder Gat and Zout River consists of dark green strongly pleochroic hornblende, plagioclase which is very much clouded by flakes and patches of sericite, quartz, magnetite and a little apatite; this rock is traversed by veins of a white granulite with dark spots due to large poikilitic dark green hornblendes without crystal faces (2306); there is a little quartz and colourless epidote in this rock, which is chiefly made of much altered plagioclase. Another specimen from the band at a point nearly south of the middle north beacon of the farm consists (2296) of a deeply coloured and slightly pleochroic greenish-blue monoclinic pyroxene, cloudy plagioclase, a little quartz, magnetite and sphene. The supposed amygdales are made of quartz, which, in strong contrast to the rest of the rock, is in large irregular grains.

These granulites are continued on the west bank of Hartebeest River in a belt some 500 yards wide on Kalk Puts, and there are at least nine parallel but thinner bands of similar rocks on Koker Berg, Kalk Puts and Zwart Puts, with a trend between north-north-west and north-west. Where hornblende becomes very abundant a schistose structure is strongly developed, elsewhere the structure is granulitic with or without discernable banding due to partial separation of dark and light minerals in layers. Many intrusions of gneiss occur in these rocks; they can be well seen on the steep escarpment of the easterly dipping granulite near the house on Modder Gat and above the road to Kenhardt.

A fairly thick belt of hornblende granulite was met with on Wit Klip and was traced for some 17 miles through Zwart Kop and the Drie Kop farms, where it gives rise to the high escarpment and ridge of granulite which is the most conspicuous feature in the landscape in the neighbourhood of Kenhardt. It bends in company with the other thinner granulite and schist bands and the gneiss of this area, and it comes to an end in a mass of pegmatite and gneiss on the low ground behind the ridges on the west side of Kenhardt Commonage.

On Onderste Drie Kop there is a flat gneiss area, with almost horizontal foliation, behind the high granulite ridge; this is the central part of a broad dome-shaped structure, which, however, is not developed with regularity on the south-west side. On the east, north and north-west the dips of the granulites, schists and gneiss are away from the central mass at moderate angles rarely reaching 45°. On the south side there is a prominent strip of quartzites dipping S.S.W. There are two large granulite belts which enter into this dome; one has been described already, and the other forms a long curved ridge, on one point of which the southern beacon of Leeuw Kop stands. A specimen from this beacon hill (2485) is seen under the microscope to be a granulitic mixture of quartz, plagioclase, pale green hornblende, epidote, sphene and magnetite; the epidote often forms narrow rims round the hornblende and magnetite. The rocks in the south-east part of this belt as well as some of those in the western part have sub-angular pieces of quartz up to two inches in length in certain layers of grey granulite; they seem to be breccias changed into granulite. Veins of gneissose granite are very numerous; they are found lying parallel with the granulite and cutting it at various angles. Owing to the comparatively rapid disintegration of these gneiss bands they give rise to *debris* covered slopes on the escarpments, while the granulites form cliffs. The belts of granulite disappear when followed owing to the increase in the number of gneiss bands within them. A thin, inconstant belt of hornblende-quartz-and mica-schists lies inside the area bounded by the two large granulite belts. Two slices (2486-7) cut from green rocks of these outcrops are made of quartz, epidote, piedmontite and a little magnetite. In one case there are fibrous aggregates of a slightly birefringent mineral, coloured brown by minute inclusions in parts, arranged in radiating bunches. The epidote and piedmontite are grown together; the former often surrounding the latter. A curious feature in one of the slices is the presence of rather large cavities in the quartz filled with a bubble and two liquids.

The gneiss between the Driekop granulites and Rooi Berg has various dips, but the strike is parallel to the strike of the Driekop rocks until the neighbourhood of Rooi Berg is reached, when it conforms to the dome-structure of Rooi Berg.

Rooi Berg is a dome of gneiss, both coarse and fine grained granulitic gneiss, surrounded by a semi-circular belt of granulite, hornblende-schist and quartzite, very like the inner belt of Drie Kop. The quartzite seen in thin section (2489) is like the rock described above, but it does not contain piedmontite. The Hartebeest River has cut through the eastern part of the Rooi Berg dome, and the continuity of the granulite belt on that side cannot be seen.

On the east side of the river at Kenhardt there are three belts of granulitic rocks containing hornblende and several thin hornblende-schist bands. The strike of all these is west-north-west, and they dip at high angles to the north-north-east. The thickest belt was traced from the river below the village for nine miles to the south-east across the farm Rooi Berg, where it makes a sharp bend to the north-west, turns back again and disappears on Mottels River. A thin band of similar rock occurs on the strike of this belt further east. A thin slice from this belt in Kenhardt village (2297) consists of rather dark green hornblende, plagioclase and quartz, with a little magnetite. The plagioclase is peculiar in having a marked zonal structure due to the varying composition of the individual grains, the central portion being more basic, judging from the extinction angles, than the outer. This feature has not been noted in any other granulite from these districts. This rock is penetrated by veins of white rock consisting of (2298) a granulitic mass of much decomposed felspar, apatite and magnetite with a little chlorite and dark brown sphene.

Many bands of hornblende-schist from 5 to 200 feet wide lie in the gneiss near Kenhardt and their course is parallel to that of the broader belts of granulite. One group of outcrops, traced through 200 yards only, is made by a thin band of cordierite-schist (2484). It consists of cordierite chiefly, with much red biotite, long prisms of sillimanite, and a little plagioclase, quartz, garnet, apatite, magnetite and green spinel.

On Mottels River there are two bands of hornblende granulite forming a horse-shoe curve open to the south, and in the middle of the gneiss within the curve there is a mass of altered limestone about 150 feet thick and traceable for some 500 yards, though it is not well exposed.

There are several varieties of the altered limestone here, that on the west side being a pale rock, from the weathered surface of which project small crystals of diopside. The thin section (2299) shows rounded or irregular areas of colourless diopside usually fresh, and altered to colourless serpentine in only a few places; the rest of the rock is made of calcite with small prisms of an undetermined mineral with frayed-out ends. In the middle of the band of limestone a small prospecting pit shows a large mass of pale greenish diopside with a vein of pegmatite cutting it. On the eastern side the limestone becomes a coarsely crystalline marble containing a few small crystals of magnetite. At the junction with the gneiss there is a narrow band of tough rock containing prisms of scapolite up to six inches in length, along with a little quartz and biotite now altered to chlorite. At a distance of about 150 yards to the east there is a band in the gneiss full of garnets up to one inch in diameter with good crystal faces. These garnets are peculiar in that the outer shell is reddish brown while the interior is paler in colour and contains epidote, diopside and some green actinolite.

Just north of the homestead on Mottel's River the outer belt of hornblende granulite referred to above is cut by a vein of pegmatite, the felspar crystals of which are several yards in length while the quartz has the pinkish colour so common in the quartz veins in the gneiss. A pecular garnet rock lies just above a band of hornblende-schist on Mottels River. It is a mottled pink, white and green rock. It looks fresh in the hand-specimen, but is seen to be altered in thin section (2358). The garnet is very abundant, and it is an unusual kind coloured in two shades of light brown with a tinge of red. The two varieties are sharply marked off from each other but form parts of the same individual crystals; the lighter coloured kind is usually in the interior. The outlines of the garnet are quite irregular as a rule, though there are small well-formed crystals. The other constituents are felspar, which is decomposed, quartz, epidote and calcite, and some green pseudomorphs after biotite. The texture is roughly granitic.

On the right bank of the Hartebeest River below Kenhardt thin bands of hornblende-schist and granulite were seen in the gneiss as far down as Ganzen Mond, the limit of field-work in that direction. The strike of all these rocks varies from east and west to west-north-west, but on Vyf Beker there is a disturbed area in which the foliation of the gneiss and the schist bands have south-easterly dips. To the north-east of

this area there is a series of four belts of limestone with various granulites, quartzites, schists and gneiss dipping conformably with them towards north-north-east. A fifth, disconnected band of limestone, lies on Vyf Beker and Leeuw Kop.

The most prominent limestone band is that on which the middle beacon common to Ganzen Mond and Vyf Beker stands; it forms a sharp ridge rising 200 feet or so from the flat ground, and it was followed through five miles, but it is continued further towards the west on Ganzen Mond. The ridge is made of coarse grained and well banded metamorphosed limestone and is about 400 yards wide at the thickest part, but thins to less than half that width although the dip remains high, 45° or over, throughout. The banding is due to the greater abundance of silicates in some layers than in others, and it gives the layers the appearance of having been due to original lamination and current-bedding. Owing to the resistance to weathering offered by the silicate grains this altered limestone, like all the others seen in the district, has a peculiarly rough surface. On a fresh surface greenish grains of serpentine give much of the rock a mottled appearance. A thin slice from within a foot of the gneiss on the beacon hill (2478) shows a rather coarse grained rock, chiefly made of calcite, with anhedral grains of olivine minerals, but without other constituents. Some of the olivine is colourless but part of the same grains may be orange-yellow in colour, in which case both varieties behave uniformly between crossed nicols. The yellow mineral, which is probably humite, occurs independently also. In the limestone there are occasional streaks and nodular masses of rock rich in silicates; their mode of occurrence reminds one strongly of the chert in the Campbell Rand beds, though they are obviously made of a mixture of minerals. A thin section of such a mass (2478) is seen under the microscope to be made of a colourless monoclinic pyroxene, probably diopside, much serpentine, with occasional olivine grains left unchanged, and a little phlogopite and calcite. There are intrusions of gneiss in this band of limestone and in the others to the north-west. The junction of the two rocks is clearly seen at several spots, and so far as one can judge from the appearances on the ground and one thin slice, taken from within an inch of the limestone, the gneiss is not enriched in lime locally. In the slice (2476) there are seen orthoclase and a plagioclase, quartz, a green chloritic mineral apparently forming pseudomorphs after biotite, and magnetite. The chlorite is surrounded by a very thin coat of a colourless mineral with higher birefringence than the green chlorite itself, which seems to be another

variety of chlorite. In this respect the specimen is peculiar, but there are no distinctive lime silicates. In the upper part of this limestone belt a layer of hornblende-schist from 2 to 24 inches thick was traced for 50 feet along the strike of the limestone. The junctions are sharp; the limestone at the contact is just like the rest of the limestone. A slice from this schist (2477) is made of actinolitic hornblende with magnetite, sphene, epidote and a little calcite; it is like several such schists in Kenhardt and is probably a metamorphosed basic igneous rock intrusive in the limestone. Green hornblende is rarely seen in the limestone of this district; tremolite is the usual amphibo!e seen in them, but it does not seem to be a common product of alteration here.

A rather thick band of limestone, perhaps a continuation of the one just described but shifted towards the north-east, extends from the low ground in the middle of Vyf Beker on to Leeuw Kop, and the third beacon from the river stands on a hill formed by it. It is much split up by hornblende-schist and gneiss, and there are large veins of pink and pale violet quartz in the complex. The limestone on the hill contains lumps similar to those noted in the Vyf Beker ridge. A slice from the limestone (2482) is made of calcite, olivine partly converted into serpentine, colourless garnet and small black grains, some of which were isolated from a piece of the rock and found not to be either graphite or magnetite. A slice from one of the lumps in the limestone (2483) shows much colourless monoclinic pyroxene which is not serpentinised, olivine and serpentine, tremolite and a little calcite.

A few outcrops of metamorphic limestone occur on the road from Kenhardt to Nrougas, to the south-east of the last-mentioned band, but whether they are part of it is uncertain. No further outcrops were seen to the east. Two slices (2360-2361) were cut from these outcrops, which are rather coarse grained rocks with small green spots of serpentine one mm. wide and plates of phlogopite two mm. wide; under the microscope no olivine is seen, and the serpentine contains hydrated oxide of iron and some black mineral, but these occur also in the calcite; the smaller serpentine grains and green spinel are often enclosed in large grains of calcite; magnetite occurs in grains independently of the serpentine; the phlogopite is practically uniaxial. The carbonate in this rock is all calcite, according to the result of an application of Lemberg's solution.

The Vyf Beker ridge is separated by a band of gneiss 700 yards wide with streaks of grey granulite in it from the next limestone band to the north-east. A mass of gneissose

granite within this second band is surrounded by a zone of pale greenish compact rock 10 feet wide. Two slices (2474-2475) from this green rock show that it is made almost entirely of grains of colourless pyroxene and scapolite with a little sphene. In one slice the pyroxenes become elongated in the direction of the prism axes, but they do not show crystal faces. The two prism cleavages are well developed.

The third limestone belt is in contact with gneiss on both sides. A specimen from the middle of this belt (2472) consists of calcite and serpentine, but the latter is spotted with an opaque brown substance. A slice from a white rock spotted with dark minerals forming a thin band between the limestone and the gneiss to the north-east (2473) consists of scapolite and strings and patches of a very pale green augite or an intergrowth of the latter with rather dark green hornblende; some epidote and irregular patches of strongly dichroic blue tourmaline are also seen.

The fourth limestone band is accompanied by other metamorphic rocks. (See fig. 2.) This limestone was traced for

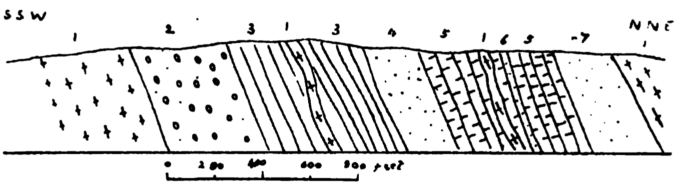



FIG. 2.—Section through metamorphic rocks on Dwaal Geesi (Part of Vyf Beker). 1. Gneiss. 2. Amygdaloidal granulite. 3. Quartzite. 4. Grey granulite. 5. Metamorphosed limestone. 6. Hornblende schist. 7. Granulite.

three miles. The bulk of the rock seems to contain olivine, green spinel and phlogopite only in addition to carbonates, the scapolite, pyroxene and hornblende were seen at the gneiss contacts and in small lumps of rock included in the gneiss. Two specimens (2464 and 2467) from the central part of the limestone show calcite, olivine, a golden yellow pleochroic mineral, like olivine in other respects, which is probably humite, green spinel and serpentine; a few of the serpentine pseudomorphs have the characteristic shape of olivine crystals, and the mineral does not contain magnetite. The olivine alters to serpentine more readily than the humite. The band of granulite (7 in the figure) is not always seen between the limestone and the gneiss to the north of it. It is a white rock with large dark patches, and in thin section (2465) is seen to consist chiefly of scapolite with pale green monoclinic pyroxene, rather deep green hornblende, sphene

and a little epidote. The pyroxene and hornblende enclose grains of the other minerals. A specimen from a spot where this band is very thin (2466) consists of scapolite and the green pyroxene, which is distinctly pleochroic, sphene, apatite and epidote. The limestone contains lumps a few inches in diameter rich in phlogopite. A thin section (2468) shows phlogopite, calcite and much green spinel, of which the central part of each grain is crowded with minute opaque inclusions. The granitic-gneiss intrusion in the limestone marked in the figure (fig. 2) does not contain special minerals ; in thin section (2469) it is seen to consist of quartz, microcline and a little muscovite. This vein encloses lumps of dark rock with splintery fracture, a thin section (2470) from one of these shows a mass of pale reddish-yellow garnet enclosing scapolite and pale green pyroxene with very little calcite.

The granulite which lies between the limestone and quartzite is a grey rock which has not been examined under the microscope ; it resembles the granulite south of the quartzite band, but it contains no rounded patches of quartz and epidote seen in the southern granulite and presumed to be amygdales.

The quartzite is schistose at places owing to the amount of mica present. It is traversed by a band of gneissose granite which breaks across the banded structure of the quartzite, though at a low angle. The granulite which lies between the quartzite and gneiss (2471) consists of grains of pale green monoclinic pyroxene, quartz, magnetite, epidote and sphene with much cloudy material which looks like decomposed felspar ; the clear elliptical and rounded spaces supposed to represent amygdales are made of quartz and colourless epidote.

On Nrougas Nord a belt of mica- and quartz-schist trends eastwards from near the homestead for about five miles and then turns north and west of north ; its continuity is broken by some two miles of ground on which only gneiss and a bent band of amygdaloidal granulite appear, but a similar belt is again seen to the north-north-west of the end of the first one and was followed on to Piet Rooi's Puts. Smaller masses of quartz-schist were found in the gneiss in the central part of Nrougas Nord.

On the northern part of the farm a remarkable group of altered limestones and granulites lies in the gneiss and is penetrated by the latter. The beacon common to Piet Rooi's Puts, Klip Kopjes and Nrougas Nord stands on a very rough hill of altered limestone which is much twisted, so that the bedding planes make sharply-curved outcrops. The dip is vertical or nearly so. Thick masses of white granulite and a

coarse garnet gneiss cut the limestone. The rough surface of the hill is due to the comparatively rapid removal of the calcite, and the alternation of layers rich and poor in silicates. A thin section of this rock (2455) shows little calcite and staurolite with much of a colourless mineral which has not been identified. In the hand-specimen this mineral is white, and it is not appreciably affected by hydrochloric acid. It has a moderately high refractive index and rather high negative birefringence; the prism cleavage is of the pyroxene type, and on cleavage flakes lying flat the extinction is always straight. It seems to be an orthorhombic pyroxene.

This rock is cut by a coarse garnet gneiss, which has a platy structure along the contact and in the vein shown on the left of fig. 3.

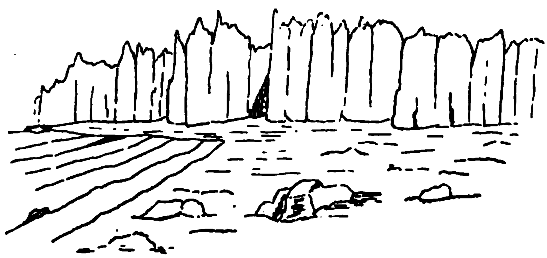


FIG. 3.—Sketch showing the intrusion of garnet gneiss cutting the metamorphic limestone on E. side of the north beacon hill of Nrougas Nord. The vertical face of altered limestone is about 15 feet high; the vertical lines are due to weathering along bedding planes.

Another rock, which may be an intrusion, on the same hill has a thoroughly granulitic structure and consists of (2456) quartz, felspar (orthoclase and microcline) grains of bright green, very slightly pleochroic monoclinic pyroxene, sphene and a little garnet and calcite.

To the south of the beacon hill there is a complicated mass of limestone and granulite, with occasional bands of gneiss and pegmatite veins. The limestone in this mass is mostly an olivine-bearing rock, but there are often other minerals present as well. A slice from a grey rock (2457) is made of calcite and rounded grains of fresh olivine, green spinel, magnetite and some opaque needles which are probably rutile. A dark granulite (2458) which crops out near the limestone just described, consists of colourless monoclinic pyroxene with immense numbers of dusty inclusions arranged in two sets of planes, one forming a very small angle with a prism cleavage and the other crossing the same cleavage cracks almost perpendicularly; the pyroxene grains are often

edged with a little green hornblende. Plagioclase is very abundant, twinned on both albite and pericline plans, and is probably near andesine in composition; it has a cloudy patch in the middle of each grain owing to the presence of very minute opaque inclusions. Magnetite and a very little biotite are present, and there are peculiar spherical patches, either of felspar with great numbers of minute magnetite crystals, or of a mixture of magnetite, epidote and zoisite.

A band of limestone which lies in granulite and has been bent into a long, closed loop enclosing a large mass of the granulite, shows the effect of the bending in its minute structure (2459); the calcite is traversed by innumerable twin planes which are bent, but the other constituents, grains of a slightly pleochroic pale green hornblende and a colourless diopside, do not exhibit strain effects. There is also some magnetite. The granulite in contact with this limestone (2460) is made of an acid plagioclase, pale green monoclinic pyroxene and much garnet, which is yellow in the interior and colourless outside; the minerals do not show strain effects, and the felspar is quite clear in the outer part of each grain, often throughout.

The limestone of the southern part of the hills is often banded in pink and grey. A thin slice from a pink band (2461) is made of calcite, olivine partly changed to serpentine, much phlogopite and a few grains of a pyroxene or wollastonite. Lemberg's test did not indicate the presence of any dolomite.

There are occasionally seen irregular lumps and streaks of silicate rock behaving like chert in this banded limestone. They are disconnected, and from the way they fill joint planes in the limestone have the appearance of chert veins and nodules. In thin section (2462) this rock is seen to be made of clear felspar which is rarely twinned, but from its refractive index must be a plagioclase, a negative biaxial mineral which is like the undetermined mineral from the beacon hill, and a few grains of an almost colourless monoclinic pyroxene.

Veins of pale granulite (2463) made of quartz, albite and small grains of pale green pyroxene and sphene traverse this limestone, and appear to be intrusions, for they cut the limestone in various directions and there is no brecciation or other sign of faulting at the contacts.

A wide area of gneiss without any thick band of schists on granulites lies between the mass just described and the metamorphic rocks of Piet Rooi's Puts and Eksteen's Kuil. Between the quartz hill at the east beacon of Piet Rooi's

Puts and the well near the north-east boundary line there are masses of compact grey rock lying in the gneiss; they reach a length of 20 feet, but are often much smaller. Their shape is irregular and their limits are sharp; they seem to be blocks "floating" in the gneiss. A thin section (2442) from one of them is seen under the microscope to be a fine grained rock with granulitic texture composed of grains of a basic plagioclase, slightly pleochroic enstatite with minute rod or plate-like inclusions in some of the grains, biotite and magnetite.

To the west of the well there is a belt of dark granulites, schists and quartzitic rocks, all of which are traversed by irregular veins containing felspar, hornblende, epidote and magnetite, often cavernous with freely developed plagioclase crystals projecting into the cavities. Many of the schists and granulites are full of distorted amygdales. A thin section (2443) from a dark schist with pale oval patches, which may be amygdales, is made of ragged green hornblende in rather large patches and also in thin prisms with sharp ends, plagioclase and possibly quartz, though all the clear areas large enough to test in convergent light gave biaxial figures, magnetite and large well-defined patches of epidote and felspar, which are the supposed amygdales.

One of the rocks taken to be an altered quartzite contains both epidote and hornblende. In thin section (2444) it is seen to be made of granular quartz, of which the largest grains are ·1 mm. wide, with minute granules of epidote and long prismatic crystals of green hornblende, also a little magnetite. The hornblende encloses quartz and epidote, and in transverse sections the prism and clinopinacoid faces are seen. This granulite belt comes to a rather abrupt end under débris-covered ground at the south-east foot of the hill, but towards the north-west it is continued through a corner of Rietfontein to Eksteen's Kuil, where it forms a prominent ridge; it is here split up by one thick band of gneiss and several thin ones. A schist with white oval patches (2451-2) from the south-west flank of these hills consists of actinolitic hornblende with granules of clear felspar, but apparently no quartz, magnetite or epidote. The clear patches are felspar grains without magnetite or hornblende. At the foot of the ridge there are thick bands of quartzose rock with many of the oval patches supposed to represent amygdales. In thin section (2446, 2448-9, 2450) four of these bands are much alike; they consist of a very fine-grained granulitic mixture of quartz, felspar, some of which is microcline and all has a very low refractive index, small grains of magnetite, very

small flakes of chlorite, and a little sphene and apatite. The oval spots are well-defined areas of large quartz mosaic. These rocks, excepting the supposed amygdales, are much finer in grain than the basic granulites and schists of the district, and they form a definite belt about 300 feet thick. To the south of this ridge, lying partly on Eksteen's Kuil and partly on Piet Rooi's Puts, there are long masses of pebbly grit and quartzite lying in the gneiss. The longest mass measured over 300 feet in length. The junctions with the gneiss are sharp, without any intervening granulite or breccia. The pebbles are of quartz and range from two inches in length downwards. In thin section (2447) the quartz areas, which evidently represent original grains, though at their contacts they interlock, average 1 mm. in diameter; the small amount of interstitial matter consists of albite, microcline, quartz, colourless garnet, muscovite, biotite and magnetite; there are also a few grains of zircon.

In the prominent range of hills, called Piet Rooi's Berg, south of Dynamite Puts (on the north-western part of Piet Rooi's Puts) the only granulitic rocks seen are garnet granulite with peculiar lenticles and irregular patches of magnetite; these reach a length of half an inch. The rock occurs in thin layers lying parallel with the foliation of the gneiss.

On Boven Rugzeer there are only thin bands of schists and granulites; the mica-schist bands are from 10 to 100 feet thick and are penetrated by veins of gneiss and coarse pegmatite.

Near Rooidam house there is an outcrop of massive granulite amongst the gneiss. It is a rather dark grey rock and under the microscope (2365) is seen to consist of oligoclase, quartz, enstatite which is slightly pleochroic, brown hornblende, biotite, magnetite, apatite and zircon. The texture is granulitic, though the grains vary considerably in size; the oligoclase, which is cloudy owing to the presence of very minute inclusions, forms larger areas than the other minerals and encloses grains of them. Apatite is the only mineral which shows crystal faces.

On Gemsbok Bult a band of micaceous phyllite and quartzitic rock 50 yards wide crops out in the gneiss. It is traversed by veins of gneiss. Under the microscope a specimen of the micaceous rock (2366) is seen to have a fine-grained granulitic texture as regards the quartz and felspar (orthoclase and microcline), but the abundant and small flakes of brownish-green biotite give it a parallel structure. Another specimen (2367) is coarser and less uniform in grain, which gives it the

appearance of gneiss, though the biotite is much more abundant than in the usual gneiss of this area. Whether these rocks should be assigned to an earlier gneissose group than the bulk of the Kenhardt gneiss or to an altered sedimentary mass is quite uncertain. They are without doubt older than the gneiss which cuts through them.

Between Zand Ruggens and Weltevrede there is an irregular band of amygdaloidal granulites much broken up by gneiss. The supposed amygdales are elongated in one direction, but in a section at right angles to this they have roughly circular outlines without noticeable compression. In the thin slice (2372) these amygdales are seen to consist of quartz, forming a large-grained mosaic, and a very few small grains of green pyroxene ; the rest of the rock consists of quartz, plagioclase, green monoclinic pyroxene, garnet and sphene. Poikilitic structure is well developed, especially in the cases of felspar and pyroxene.

A broad belt of granulites with layers of gneiss stretches from the south-east end of the Zand Ruggens dunes through the north-eastern part of Kantien Pan. A peculiarity of this belt is the occurrence of a white granulite spotted with large poikilitic black masses of hornblende. In thin section (2373) this rock is seen to consist of quartz, oligoclase, dark green hornblende, garnet, biotite, sphene, epidote and apatite. The apatite alone has idiomorphic outlines.

### *The Kaaien Beds.*

The main range of the Brakbosch Poort hills comes to an end on the farm Karos within two miles of the Orange River in the manner already described (see p. 15). The structure of this extremity is evidently that of an anticline, but an area of Wilgenhout Drift beds and granite about two miles wide separates this anticline from the high quartzite hills made of Kaaien beds dipping steeply toward the south-west on the west side of Karos and the neighbouring part of Matjes River. A smaller mass of quartzite striking parallel to the anticlinal axis lies between the two groups of hills, but except that it is in contact with the Wilgenhout Drift beds on the north-west and east, and with the mass of granite that invades the Wilgenhout Drift beds on the north-west, its relation to the ranges is uncertain. The southern part is wrapped round by sand, which effectually conceals the rocks on the southern corner of Karos, where the two ranges approach within a mile and a half of each other. There is a wide exposure of granite on the north-eastern part of Trooilaps Pan in a position which seems to indicate the extension of the granite between

the two ranges. The western range on Karos is narrow in the south-eastern portion of its length, and two granite and gneiss areas lie close to its western side, but towards the river it broadens out and becomes one with the quartzites and schists which are cut through by the Orange River for 11 miles below Baviaan Kranz, with only one break due to the intervention of a mile-wide strip of gneiss and grey granulite on Matjes River. This gneiss and granulite was not recorded on the right bank of the Orange River in 1907, but whether it was overlooked then or comes to an end in the broad river bed is uncertain. Two other tongues of gneiss nearly reach the river on the western part of Matjes River, and, in all, eight large strips of granite or gneiss, either entirely surrounded by the Kaaien beds at the present surface or in direct continuity with the great area of the Kenhardt gneiss, were found in the quartzites and quartz-schists between Upington and Karos. Of these only one, a two-mile strip of gneiss which traverses the junction of the Wilgenhout Drift and Kaaien beds on Karos, clearly cuts across the divisional planes of the quartzites. As is usually the case in the country made of the Kaaien beds and granitic rocks, the hills are formed almost entirely by the former while the latter occurs on low ground, though the streams often traverse, or rise on, a granite area and cut through the quartzite hills.

The great bulk of the rocks attributed to the Kaaien group in this western area are quartzites and quartz-schists; mica-schists do not seem to be very abundant, though there is of course no precise distinction between them and the quartz-schists. Occasionally, as on the north-western part of Matjes River, there are grey granulites which in many cases are obviously different rocks from the quartzites owing to the large amount of felspar in them, but there are large bands of rock which are not so easily distinguished from the quartzites, and it was often impossible to decide upon a definite boundary between the sedimentary quartzites and the rocks with approximately the mineral composition of granite. Both these granulites and the quartzites are traversed by small veins of coarse muscovite-granite and large and small dykes of hornblende-schist. The strip of granitic rocks on the river front of Matjes River contains numerous inclusions of granulites, quartzites and mica-schist, and veins from them run through these inclusions.

In the quartzites of Matjes River there are numerous small masses of granite, more or less lenticular in shape, with their longer axes lying parallel to the strike of the quartzite. These range from a few feet to 100 yards in length. One of them is represented in the plan on fig. 4. The whole mass is only

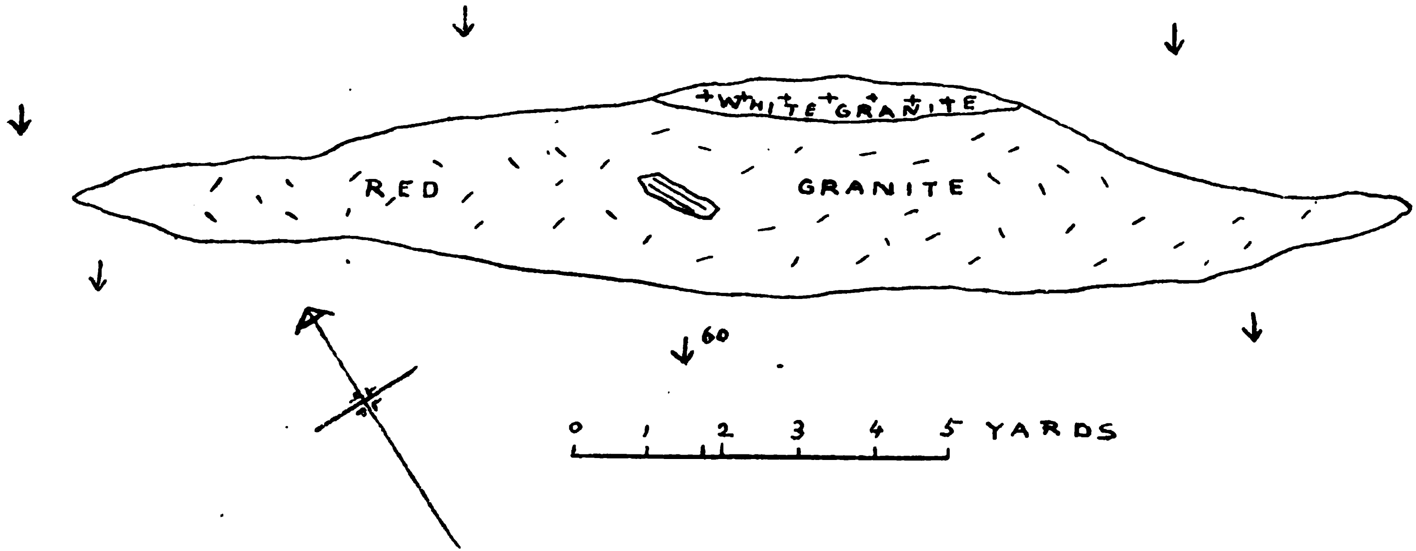



FIG. 4.—Plan of granite intrusion in quartzite on Matjes River. The red granite encloses a lump of quartzite. There is a narrow body of coarse white muscovite granite on the N.E. side of the red granite.

17 yards long, and it consists chiefly of a red granite with very slight trace of parallel structure. The white muscovite granite on the north-east side is evidently another intrusion related to the pegmatites. The red granite encloses a piece of quartzite. The dip of the quartzite is at a high angle to the south-west. The limit of the granite in these small patches is quite sharp; there is no granulite between the granite and quartzite, nor is there any sign of brecciation or drawing-out of the constituents as there would be were the position of the granite due to intense folding. These masses must be regarded as intrusions, and the pieces of quartzite in them as pieces detached from the wall when the granite was liquid. Such small pieces of quartzite are probably analogous to the large masses of quartzite lying surrounded by granite and gneiss not far from the connected quartzite ranges, such as the quartzite ridge on the south-western part of Vaal Kopjes. This mass is about four miles long by rather more than half a mile wide, and it is separated by gneissose granite from the hills to the north-west. Whether this ridge and many like it on the west side of the great range of hills made by the Kaaien beds owe their isolation entirely to the gneiss having detached them from the larger mass or whether folding assisted in the process at the time of the intrusion is a difficult question to answer decisively, but there seems to be good ground for the belief that the folding and intrusion went on at the same time; otherwise one would expect the gneiss to traverse the strike of the quartzite more frequently than it does.

On the east side of Matjes River there are bands and patches of quartzite coloured green owing to the abundance of epidote.

The general structure of the quartzites and schists below Baviaans Kranz was not made out. The strike lies between N. 15° W. and north-west, and the dip is either towards the south of west at high angles or is vertical. Rarely there is a sharp twist out of the usual direction, but the latter is resumed after a few hundred yards. One of the sharp bends takes place at Baviaans Kranz and affects the Wilgenhout Drift beds also. Baviaans Kranz is in the north-western corner of Karos, and the junction of the Kaaien and Wilgenhout Drift beds runs north-north-west towards the river, but before reaching the bank turns towards west-north-west for about half a mile. In the Kaaien beds here and within 1,000 feet of their limit there are two bands rather rich in magnetite, so that they have a dark grey or black colour. One of these, in all about eight feet thick, is made up of alternating dark and light bands rich and poor in magnetite; in the other, which is four feet thick, the magnetite is more uniformly

distributed. A marked characteristic of these bands, and of the other magnetic rocks in the Kaaien beds, is that they do not have brown, yellow or red tints, as is so frequently the case with the magnetite-bearing rocks of the Wilgenhout Drift, Marydale, Kraaipan and Griquatown beds.

This mass of Kaaien beds is continued across the Orange River in the hills which stretch through the north-east corner of Upington Commonage.

From the occurrence of the Wilgenhout Drift beds between this western mass of Kaaien beds and the end of the main range it seems that there is an overturned syncline there, as represented on the section in fig. 5.

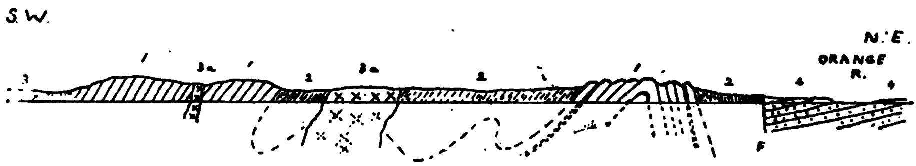



FIG. 5.—Section 11·8 miles long through the north-western part of the anticline of Kaaien beds on Karos, to show the possible relation of those rocks to the Kaaien beds further west. 1. Kaaien beds. 2. Wilgenhout Drift beds. 3. Granite and gneiss. 3a. Granite and gneiss which cut the Wilgenhout Drift beds as well as the Kaaien. 4. Koras series. F. Fault.

The distinctly anticlinal structure of the main range on Karos is only discernable for about five miles to the south-east of the termination. Then the range widens out, at first gradually, and at about 12 miles from the end more rapidly, and the Wilgenhout Drift beds are no longer seen on the west side.

On the farm Wilgenhout Drift the beds in the main range dip westward throughout, except in the high hills overlooking Groot Drink, where there is a steep easterly dip towards the Wilgenhout Drift beds. On following this boundary across Stof Gat the dips become reversed, and the Wilgenhout Drift beds dip at high angles under the Kaaien beds. On the north-eastern side of the Groot Drink mountain the beds dip north-east under the limestone and slates, but the Koras basaltic rock soon covers up the actual junction and remains in contact with the Kaaien beds for several miles to the west and north-west. A gap of a few hundred yards separates the quartzites and schists of Groot Drink mountain from a narrow strip of quartzite lying between the basalt and the Wilgenhout Drift beds further north. Another narrow ridge of white

quartzite and schist rises from the flat ground made of Wilgenhout Drift beds north-east of Boom River. It is also in contact with the basic and acid rocks of the Koras group at its north-west and south-east ends respectively. Whether this is a sharp anticline could not be determined.

The Koras formation and faults complicate the boundary on the middle portion of Stof Gat, but on the south-east side of that farm the succession may in part be a normal one, though the actual junction is concealed by *debris* to a great extent. The Wilgenhout Drift beds flanking the quartzites are very much disturbed near the river, but becomes less disturbed as they are followed south-westwards and round the projecting mass of quartzite which indents the boundary between the two formations. To the south-west of this point the dips seem to be conformable, but to the north-east the Kaaien beds dip in a more northerly direction than the Wilgenhout Drift beds, which therefore abut against the former. This effect is due to a continuation of the Sterkstroom and Groot Drink fault.[1] which was found on the other side of the Orange River in 1907. The diabase intrusion near that fault does not cross the river on to Stof Gat. The structure of the north-eastern part of Stof Gat is apparently synclinal, with the axis lying somewhat east of north and inclined in the same direction. The fault affects the south-east limb of the syncline, the Wilgenhout Drift beds of the syncline being let down relatively to the Kaaien. The apex of the V-shaped boundary between the two formations is covered up by the Koras series, which is again faulted along north-south lines with down-throw towards the east.

It is about this syncline that the great divergence of strike between the beds of the Brakbosch Poort hills (north-north-west) and those of Keuken Draai and the Buchu Berg (east of north) is first met with going up the Orange River, with which the great widening of the area occupied by the Kaaien beds below Buchu Berg is connected.

Along the western flank of the main range the strike never turns far from north-north-west, but on the east side of the range the strike varies frequently on the low ground near the river and the hills on it. The beds dip in various directions in this area, and the structure is evidently very complicated, yet neither the Marydale nor the Wilgenhout Drift beds were seen between the western side of the range on Klein Begin and Buchu Berg, a distance of over 30 miles.

---

[1]Ann. Rep. Geol. Com. for 1907. p. 37.

On the eastern side of Trooilaps Pan five ridges of quartzite project from the sand on the west side of the main range. In one of these there are thin layers of grey granulite intercalated with quartz-schist. They do not break through the schist so far as they can be followed, and they have the appearance of quartzite with felspar in it, but in thin section (2430) the rock seems to be a granulitised granite made of oligoclase, orthoclase, quartz, biotite partly chloritised, a little muscovite, magnetite and apatite; the orthoclase is cloudy with alteration products, but the minerals are mostly fresh and do not show strain shadows. These rocks are in thin bands and have sharp junctions with the quartz-schist or quartzite in contact with them.

A remarkable rock of a type not seen elsewhere in the district forms a band nearly 200 feet thick in one of the Trooilaps Pan ridges. It is mostly covered with fragments of the quartzites amongst which it lies, but so far as it could be traced it did not seem to cut the quartzites. In hand-specimens it is a mottled pink and green rock; the pink parts are large straggling nodular masses and layers of garnet; cleavage faces of a chloritic mineral and of epidote and a rhombic pyroxene are seen in the green parts. Under the microscope (2431) the portion of the slice from a pink mass consists of garnet without crystal faces enclosing numerous minute patches of epidote as well as other minerals which have not been determined; the rest of the slice consists chiefly of grains and ill-formed crystals of epidote, a few prisms of a slightly pleochroic pink and greenish mineral, enstatite presumably, though a good transverse section showing the intersecting cleavages was not found. In optical character the mineral agrees with enstatite, though the double refraction is rather high for that mineral. Some calcite and a chloritic mineral are also present.

South-east of Trooilaps Pan twelve elongated masses of Kaaien beds, or rather of quartzites, quartz- and mica-schist assigned to that group, were found lying at some distance from the main range and separated from it by granite or sand. Where sand alone intervenes at the surface it is probable that granite or gneiss exists immediately under it, for small outcrops of these rocks were often found in such situations, and wells sunk through the sand have exposed them.

The main range was followed from Karos to Put Zonder Water, a distance of rather over 50 miles. It was ascended at seven places in that distance, and good sections through it were seen at Vaal Kloof and between Boks Puts and Weg Draai. The rocks are very similar throughout, quartzites

and schists with more or less mica, occasionally with enough magnetite to give them a dark grey colour, or enough epidote to give them a green tint. The strike is north-north-west, and the dip usually towards west-south-west, but occasionally an anticline or syncline was noticed. The dips are very rarely under 50°, often over 80°, and no clear evidence of the general structure was obtained.

The surface of the range is very rough and the soil scanty, in spite of which the mountain ground on each farm is valuable for grazing in times of drought, when there is enough vegetation on it to keep alive stock which would perish on the low ground to the east and west.

### *The Wilgenhout Drift Beds.*

These beds were seen in three separate areas, the first extends through Stof Gat and Wilgenhout Drift, and is continuous with that described in Gordonia[1]; the second is a narrow strip on Zwart Kop and Karos, and the third is the large area on Karos which wraps round the anticlinal axis of the main Kaaien range.

As stated above, the Wilgenhout Drift beds form a synclinal wedge-shaped area on Stof Gat, but the fault within the syncline found on the right bank of the river was not seen again on the left bank in Kenhardt.

The rocks are of the same types as those seen in Gordonia, but limestones, conglomerates and felsites are less abundant on the Kenhardt side of the river. The greater part of the rocks are sheared green lavas and slates, and interbedded with them lie bands of grit, quartzite, quartz-porphyry, breccias and limestones. The nature of the ground is not favourable to the following up of particular beds, for the whole group lies in a valley between high hills from which the surface is plentifully supplied with *debris*, yet in the case of the most resistant rocks, the red quartzites very like those of Zwart Kop on the Gordonia side, it is seen that the short outcrops represent all there is and that these rocks occur as lenticular masses surrounded by the softer green slates. The most prominent kopje in the area stands in the middle of the valley, rising some 80 feet from flat ground made of green slates covered by coarse angular gravel. It consists of two lenticles of red quartzite separated by a thin layer of green slate. The larger is 500 yards in length by about 50 feet in thickness, and the shorter one is 30 feet thick. The rock is a dark red ferruginous quartzite which is frequently cavernous, and at

[1] Ann. Rep. Geol. Com. for 1907, pp. 35-42.

one place a thin band of breccia made of quartz and dark quartzite fragments in a red quartzite matrix. With this exception, which may be a crush breccia, the rock is like that of the Gordonia Zwart Kop.[1]

The actual contact with the green slates is not exposed, and the dip is very steep towards west-north-west, but from exposures in ravines it is certain that the quartzite is not continued along the strike far from the outcrops. A third quartzite makes a small kopje a mile south-south-west of the large one, *i.e.* on the strike of the latter, and another group of red quartzite outcrops occur about 1½ miles to the north-east amongst sheared amygdaloids and breccias. A thin section from a gritty red quartzite in these outcrops (2377) is seen to be made of angular and subangular grains of quartz, chert, acid plagioclase, microcline and a little white mica set in a quartz matrix with some calcite and red iron oxide. The felspars are slightly clouded, but the rock shows no special features due to pressure. This freedom from changes due to pressure is a marked characteristic in some of the other grits examined, though there is no doubt that they have shared in the events which left such characteristic effects in the sheared green rocks and the limestones, and also in some of the quartz-porphyries.

Thin beds of red quartzite, not over six feet thick, were traced for as much as 300 yards along the strike within 500 yards of the supposed overturned base of the Wilgenhout Drift beds on the north-west limb of the syncline. The dip is vertical or very high to the west-north-west. The associated beds are green sheared lavas and slates with occasional outcrops of grey limestone. Porphyries were not seen here.

Several outcrops of quartz-porphyry are to be seen amongst the green slates on the south-east part of Stof Gat. So far as the limited exposures afforded by the banks of a ravine allow the relations of the rocks to be studied, the porphyry lies parallel with the cleavage of the slates. The thickest porphyry exposed is four feet thick; in thin section (2378) the matrix is seen to be a very fine-grained mixture of quartz, felspar, magnetite and haematite, and it encloses broken-up quartz crystals and comparatively fresh crystals and rounded areas of orthoclase and plagioclase. There is very little muscovite in small flakes, perhaps of secondary origin, and some calcite in cracks. This is a different-looking rock from the white porphyry found on the Gordonia side of the river,

[1] Ann. Rep. Geol. Com. for 1907, p. 40.

and, on account of the thinness of the layers, it is extremely doubtful whether it is a volcanic rock. Probably these thin quartz-porphyries are intrusions.

There is a band of porphyritic rock very near the base of the group on Wilgenhout Drift, just east of a thin ridge of quartz-schist projecting north-north-west from the quartzite and schist mountain behind Groot Drink, though there is no connection between them at the surface, for there is a gap of several hundred yards where the Koras basic intrusive rock is in contact with the Wilgenhout Drift beds. No porphyritic quartz was seen in this rock, which is greenish with small porphyritic felspars scattered through it. In thin section (2387) the crystals are seen to be of a microperthite, probably orthoclase and a plagioclase; the rest of the rock consists of very small quartz and felspar areas with much greenish mica and sericite in very small flakes.

The limestones often occur near the supposed base of the group. To the east of the porphyry just described there is an irregular but rather thick band of yellowish limestone or calcareous grit, interbedded with which are thin layers of green slate. In thin section (2388) the proportion of carbonates is seen to be small and stained with rusty iron oxide; the other constituents are quartz and felspar grains, often angular, and small flakes of white mica, which looks like an original constituent and not a product of alteration. A second band of limestones, associated with sheared green lavas, slates and conglomerates lies about half-a-mile to the east. The limestones are again seen further north, in the narrow strip of ground between the isolated quartzite ridge which runs north-west and ends in the hill near the river, on which stands the beacon of Zwart Kop and Wilgenhout Drift.

On the south-eastern part of Stof Gat limestones were only seen in lenticular beds of small extent, though many of the green slates in the neighbourhood contain much calcareous matter, chiefly in the form of veins. The limestone is a grey rock with larger calcite grains than are usually seen in the Wilgenhout Drift limestones; pyrites is visible in the hand-specimens. A thin section (2380) shows that tourmaline is abundant in minute, well-formed blue prisms. The calcite is in large and small grains, and there is a fair amount of granular quartz and some black grains of irregular shape. The tourmaline is chiefly seen along the contact of the large calcite grains, but it also occurs in the fine granular calcite. The tourmaline in this rock is certainly of secondary origin, but it seems difficult to connect its occurrence with any visible

intrusion, unless the quartz-porphyry, supposed to be intrusive, was concerned in its production. No outcrops of this porphyry were found in contact with the limestone, but some occur within 300 yards of it. The nearest gneiss intrusion seen lies more than three miles to the west. Tourmaline has not been seen in other rocks of the Wilgenhout Drift group.

The conglomerates seen on the Kenhardt side are very much thinner than those on the Gordonia bank of the Orange River. They contain pebbles of quartz and quartzite. A thin bed of conglomerate is seen in the hill about a mile north-west of Groot Drink associated with grey quartzites and green, gritty schistose rocks. These beds are traceable for a few hundred yards only, when they are replaced by green slates. Some conglomerate outcrops are seen near the river south of Groot Drink amongst alluvial silt.

The sheared green lavas with amygdales are very abundant in this area. Probably much of the green slate is derived either from lava or volcanic tuff. They are like the rocks described from the Gordonia bank of the river in the Report for 1907, and they have not been cut for the microscope.

The breccias and gritty tuffs accompanying the lavas are well developed near Stof Gat homestead, where there is one band over 300 feet thick containing fragments of green slates, reddish grits and quartzites, green lava and vein quartz. Some of the lava blocks are a foot long. A thin section from a fine-grained portion of the breccia (2381) contains angular fragments up to half-an-inch in length ; the fragments in the slice are siliceous (cherty) limestone, fine-grained quartz-sericite schist, an andesitic lava made of small lath-shaped crystals of oligoclase lying in a matrix of chlorite quartz and epidote, a quartz-felspar grit, and quartz-chlorite schist ; the matrix is rather scanty, and consists of quartz, epidote and some calcite. A specimen taken from a tuff band which lies parallel to the rough bedding of these breccias and the slates, just to the west of the thick breccia mentioned above, shows very remarkable features ; when seen in the field as an uncleaved grey rock with visible felspar fragments no suspicion was entertained that it might not belong to the Wilgenhout Drift beds, but the fresh state of the augite fragments as seen under the microscope makes one doubt whether it does belong there. In section (2382) the matrix is amorphous and nearly opaque, but occasionally chlorite and epidote are recognisable ; the fragments are of plagioclase, augite, quartz, cherty limestone, quartz-chlorite schist and a quartz-magnetite rock. The plagioclase and augite are the most abundant fragments ; the former is much altered, but

parts are still fresh and are referable to labradorite; the augite is colourless and quite fresh; both these minerals often occur as crystals with slightly-rounded corners. As such fresh augite has not been met with in the lavas of the Wilgenhout Drift group, and as those lavas would seem to have been of a less basic nature than the rock whence the labradorite and augite of this tuff came, it seems likely that the latter really belongs to the Koras group and fills a fissure along the strike of the Wilgenhout Drift beds. The recognised basalts of the Koras group crop out within two miles of this tuff, and some thin dykes of a fresh-looking basic rock cut through the thick breccia described above.

Near the Groot Drink store (on the north-west corner of Stof Gat) there is a considerable thickness of fine-grained green rock, slightly banded at places, but without cleavage planes, invaded by the Groot Drink diabase, the non-porphyritic part of which it resembles rather closely, for both rocks weather spheroidally. When followed away from the intrusion the cleavage planes become pronounced. Two slices were cut from the green rock; one of them (2383) consists of small fragments of quartz and felspar in a greenish laminated matrix chiefly of indeterminate material with some calcite, chlorite and epidote; the other (2384) is a similar rock with more felspar, some magnetite and a few small fragments of devitrified lava having minute amygdales of chalcedony.

The narrow strip of green slaty rocks on Zwart Kop and Karos, overlain unconformably by the porphyritic rocks of the Koras series on the south-west and bounded on the north-east by faulted down conglomerates of the same series, can be assigned to the Wilgenhout Drift beds. They are micaceous grits and greenish slates, with very high northerly dips. There are rocks like them in the larger area on Karos, described below.

As explained on a previous page, the Wilgenhout Drift beds wrap round the north-west end of the Kaaien anticline on Karos (see p. 15), and the relationship seen there is of fundamental importance in fixing their stratigraphical position.

The bulk of the Wilgenhout Drift beds here are green slaty rocks, often with pulled-out amygdales. Some good exposures are to be seen round about the end of the Kaaien anticline. In these there are lying in the slates lenticles of unsheared lava several feet in length with distorted amygdales. A slice from one of these (2421) shows quartz

and epidote amygdales in a confused mixture of uralite, quartz and epidote.

The occurrence of a ferruginous impure limestone about 10 feet thick on a horizon 250 to 300 feet above the apparent base of the series, well seen on the north-east side of the Kaaien anticline is of intreest, because limestone in an analogous position occurs on Wilgenhout Drift.

The wide area between the quartzite anticline and the quartzites of the west side of Karos is a tract of gently-undulating ground with occasional outcrops of green slates and sheared lava. The rocks are poorly exposed, and some of them can be seen best in the bed of the Orange River at Baviaans Kranz, where, however, lavas were not found in the rather short space left uncovered by the water. The rocks seen in the river bed are sheared grits, greenish in colour, and some highly-sericitic beds.

In the south-western part of this area two masses of granitic gneiss traverse the slates, approximately parallel to the bedding and cleavage. The smaller of these is only about 200 yards wide and enters the Kaaien beds also ; the larger is nearly a mile wide and does not cut through the latter.

The Wilgenhout Drift beds of this area are bounded on the south partly by a ridge of quartz-schist with parallel strike which projects into them but is separated from them on the north-east by the band of gneiss just mentioned, and partly by the sand-veld of the southern portion of Karos.

## The Granite and Gneiss.

Granite and gneiss cover a very large area in the Kenhardt district between the Orange River above Upington and the edge of the Karroo formation on the Bosch Bult. Their relation to the Kheis series suggests that the folding of the latter was accompanied by the intrusion of the granitic magma, for the foliation when present lies parallel to the strike of the sedimentary beds, and an examination of the gneiss makes it quite impossible to believe that the foliation was imposed upon an already solid rock. Such a process must leave conspicuous signs in the form of autoclastic structures, but the brecciated bands in the granite and gneiss are well defined narrow bands and do not cover wide areas.

There are many metamorphic rocks in the area that have been strongly folded and re-crystallised ; these are the basic and acid granulites and the limestones of the Marydale series. Many of the basic granulites were certainly of volcanic origin, lava flows and intrusive sheets and dykes of basic composition. Though these are often seen to be made of minerals commonly

found in basic rocks of igneous origin, the relations of the minerals to one another are absolutely different to those in normal igneous rocks of similar composition. In the process of re-crystallisation the usual order of separation from the magma followed by the different minerals has not been observed; generally speaking, the anhedral grains of which the granulites are made have formed simultaneously, garnet being the only mineral which at all frequently shows crystal faces. In the granite and gneiss, on the contrary, the order of crystallisation of the minerals is usually normal. The acid granulites, several of which have been described on previous pages and in the Report for 1908, often have a mineral composition similar to that of the granites, and are undoubtedly re-crystallised rocks older than the granites of Kenhardt, but their original nature is obscure. Their separation in the field from the sedimentary schists and quartzites is difficult; and while it is easy to imagine that they are rocks of that kind impregnated with additional material from the granite magma which went to form the felspars, it is not easy to understand why a process, which has not greatly affected the limestones and basic igneous rocks invaded by the same magma, should have enriched the quartzites in felspar and other constituents. Some of these acid granulites can be regarded as altered sediments which contained felspar; but others, it seems, must be granulitised intrusive rocks of the composition of ordinary granites.

When granulitization can be seen in the gneiss of Kenhardt it affects the larger quartz and felspars partially or wholly, but the mica retains its original characters with the exception of the bending induced by pressure; the original felspars of the "eyes" in gneiss are converted into a mosaic of felspar without transference of material from the "eyes" themselves, which then have a fine-grained granular appearance in hand-specimens instead of presenting the usual large cleavages of the unchanged mineral. In a tract about two miles long on Vyf Beker this transformation is admirably exposed in all its stages, but the rock in the most advanced stage has still the same general appearance as the coarse augen-gneiss which evidently represents the former condition of the whole body of rock.

The question of the existence of granitic rocks in this area which are older than the Kheis series, and therefore much older than those which invade the latter, has not been decided. Their absence cannot be proved and would be difficult to explain. Possibly some of the acid granulites represent such

rocks. Up to the present time, however, the field work has not shown either that there is an unconformity between the acid granulites and any member of the Kheis series or that fragments of the granulites are enclosed in the latter.

There is another question unsettled, as to whether all the granitic and gneissose rocks belong to one and the same period of igneous activity. In this, as in all other great areas of such rocks there are veins of coarser and finer-grained material cutting through the usual types of rock, but such veins probably came from the same magma as the latter and were the result of a late phase of the one period of activity. The mere presence of granitic rocks both with and without parallel arrangement and banding does not give the desired evidence, for in many cases the massive variety forms patches within the gneiss, and the one grades into the other. By far the greater part of these rocks in Kenhardt is foliated, but the massive granite is more prone to appear in kopjes than the gneiss, on account of its greater power of resistance to the weather, hence many prominent outcrops are of massive granite, while almost all the rock between them is gneiss. In every case where the conditions admitted of investigation the massive granite graded into gneiss. In some instances, such as the Boks Puts well, where coarse granite with red orthoclase crystals occurs, the most striking massive varieties of granite could not be followed up.

It is impossible to sum up briefly the general characters of the granitic rocks of Kenhardt, for there are many varieties, and over wide areas outcrops are few and deeply weathered, so that it is difficult to recognise the precise nature of the underlying rock.

As a rule the area occupied by these rocks is one of very slight relief; it is gently-undulating ground of the kind called "the Bult" locally, and most of the ridges and hills in it are due to the presence of hard quartzites and other resistant rocks of the Kheis series. Towards the Hartebeest River, however, where there is better opportunity for the transport of soil and sand by water than elsewhere, there are more pronounced inequalities in the surface of the granitic rocks than elsewhere. The granitic hills which stand a long distance from the river are all made of less well-foliated rock than the surrounding gneiss, but traces of foliation are often to be seen in the hills themselves. Then, again, the pegmatites and masses of quartz, which appear to be of the same nature as the pegmatites, often give rise to small kopjes and occasionally to hills of considerable size, such as Brand Kop, on which one of the Angelier's Pan beacons stands.

In the south-eastern part of the granitic area, which includes the Brakbosch Poort Field-cornetcy of Prieska, there are very few granite outcrops, the rocks from wells and in the outcrops are distinctly foliated. The presence of gneiss and granite over such a large area is proved by the fresh cleavage fragments of orthoclase or microcline which cover the surface and are very conspicuous where the sand or soil contains coarse grit. Fragments of graphic granite are frequent; they are derived from veins and patches in the gneiss. Thin strips of dark rocks, either hornblende-schists or granulites are occasionally noticed in the gneiss. They are only a few feet wide and cannot be traced for more than a few yards; they resemble rocks described under the Marydale beds and are perhaps fragments of that formation. It is in this region, from Nels Poortje northwards, that the exposures of the Kaaien beds and the gneiss are frequently seen at such short distances apart that there is no room for the occurrence of a belt of Marydale beds along the western flank of the Kaaien beds. Another explanation of the strips of basic schists is that they may be altered dyke rocks. They do not appear to be the result of differentiation of the magma which solidified mainly in the form of the gneiss. Occasionally acid rocks of a very different character from that of the granite and gneiss are met with in similar masses. The origin of those rocks is doubtful; they resemble altered porphyries that have been regarded as acid lavas and described under the Marydale beds, but these thin dyke-like strips are isolated and so limited in extent that it is difficult to put them in the same group.

In the gneiss, about two miles west-south-west of Doonies Pan house there are narrow outcrops of an altered porphyritic rock which cannot be more than three feet wide; it must be a strip lying in the gneiss. It is a fine grained grey rock with rounded crystals of quartz and felspar. Under the microscope (2324) the matrix is seen to be a very fine grained hornfels-like mixture of quartz, greenish-brown biotite, garnet and magnetite; this encloses rounded pieces of quartz, felspars and sphene. At least two kinds of felspar, orthoclase and a plagioclase, form the rounded crystals looking like the corroded phenocrysts in quartz-porphyries. The orthoclase often encloses in poikilitic fashion rounded pieces of quartz and plagioclase, and also very many small elongated pieces of a more highly refracting colourless substance, probably a plagioclase; these small inclusions are distributed irregularly through the orthoclase, but almost all of them are elongated in the same direction. Rather large flakes of biotite are also enclosed

by the felspar. The grains of sphene are surrounded by a narrow zone of magnetite. There are also some grains of a deep green pleochroic mineral in the rock; it looks like a hornblende but wants the characteristic cleavages, and it has not been determined.

A very similar rock occurs on Put Zonder Water, in narrow bands, with rather coarse granite between them. In thin section (2331) one of the rounded felspars is seen to be microcline, and there is some apatite. In both these rocks there is a very faintly marked flow structure due to the disposition of the groundmass minerals. The rock associated with the Put Zonder Water porphyry has a coarser matrix of quartz-felspar and biotite, with well defined patches of micrographic intergrowth of quartz and felspar; there is very little magnetite (2330). There are small irregular crystals and rounded fragments of quartz, albite and microcline.

The northern beacon of Angeliers Pan stands on a rounded hill called Brand Kop, which has gentle slopes. The hill itself is a large mass of coarse pegmatite made of microcline and quartz, with a few scattered flakes of muscovite. The surrounding rock is biotite-gneiss, the foliation planes of which strike north-north-west, and biotite-garnet-gneiss with the same strike. As is always the case with the large pegmatites, the actual limit is difficult to find, owing to the quantity of fragments derived from the rock forming the higher part of the hill creeping down the slope and covering the boundary. The microcline crystals are of large size, for the loose blocks which lie in the soil are always parts of one individual so far as the microcline is concerned. In the hill east of Brand Kop great masses of white quartz are associated with the pegmatite.

To the west there are large areas of biotite gneiss with porphyritic orthoclase between Brand Kop and the Kombaers Brand well. On the rise north of the well, granite veins cut through the dark granulite described on page 29. This granite is poor in micas and white in colour; in thin section (2333) it is seen to consist of quartz, orthoclase, plagioclase of the oligoclase-andesine group, a very little muscovite, chlorite and blue tourmaline; the texture is of the granitic type.

To the north of the road, where it crosses the Kombaers Brand–Steyns Puts boundary, there is a remarkable mass of quartz and microcline in a coarse biotite-granite, with slight traces of foliation. Parts of the mass consist of microcline without quartz over many square yards, and single cleavage planes can be followed for many feet. There are wedge- or

vein-like intercalations of pegmatite in the mass, due to the appearance of quartz intergrown with the microline, and then again large masses of quartz without much felspar. The quartz of the pegmatite is almost colourless and semi-transparent, but as the felspar diminishes in quantity the quartz becomes milky and pink, and with the pink quartz there is a little pink felspar. No tourmaline was found in this mass, and that mineral was not found in any of the pink quartz which is very frequently seen in the southern part of Kenhardt, east of the Hartebeest River, though black tourmaline is often abundant in the masses of white quartz throughout the granite rocks of the district.

The large masses of pink quartz give rise to slight hills, and the farm beacons are often placed on them. The pink colour is not uniformly distributed in any of the quartz masses, but affects irregularly-shaped areas and there is a gradual transition into the white quartz.

Between the two homesteads on Steyns Puts there is a kopje with a beacon on it ; the kopje is due to the presence of microcline-quartz pegmatite and pink quartz, but with these minerals there are layers of black mica separated by sheets of quartz and microcline. The biotite occurs as aggregates of large crystals up to six inches thick across the cleavage, and the whole thickness of a layer does not much exceed six inches. Another mineral which has not been identified occurs with the pegmatite ; it forms lumps bounded by felspar or quartz ; it is very dark brown or black in colour and has a bright resinous lustre and sub-conchoidal fracture. In thin chips, under the microscope, it is transparent and brown in colour, and quite isotropic. No recognisable cleavage faces were seen on it, nor on other specimens of what is apparently the same mineral from Nrougas Nord and the well to the south-east of Steyns Puts mentioned below. A chemical examination, which Dr. van der Riet, of Victoria College, Stellenbosch, kindly made, proved that the mineral is not a silicate but contains a large amount of titanium and some iron. Its specific gravity is 4.93. The surface exposed to the weather is covered with a very thin film of dull brown substance. In a thin section cut from a piece of the Steyns Puts mineral (2500) the colour is yellowish-brown, but there are small patches of colourless substance with the same high refraction and lack of influence on polarized light as the brown parts. The section shows two systems of incipient cracks, along which the mineral has begun to change into a dull opaque substance, crossing each other nearly at right angles.

In a dry well, about six miles north-east of Steyns Puts,

the same mineral occurs in quartz veins in association with fluor and calcite. The veins traverse red gneiss which shows signs of shearing subsequent to its consolidation.

At the east beacon of Steyns Puts, overlooking the Mottels River, there is a long quartz vein, pink in places, and at one point it includes big white felspars.

A peculiar vein was found in the gneiss on Rietfontein, about one mile west of the homestead. It is a reef of white interlocking quartz crystals, but differs from other reefs in this district in carrying pink felspar, thus recalling the veins at Prieska Poort.

The granulites and schists all along the Hartebeeste valley are seamed with pegmatite and graphic granite, and one vein, close to the road to Kenhardt where it enters the farm Zout Rivier, carries large black hornblende crystals over an inch across, which include small areas of felspar in the manner known as poikilitic.

The dome-shaped mass of gneiss in Rooi Berg has already been noticed in connection with the metamorphosed sediments associated with it and striking parallel with its foliation planes (see page 33). The gneiss has a platy structure on the surface and breaks up in great slabs, but where the unweathered rock can be seen, as in the large quarry near the broken dam, the slight differences in composition and size of grain between successive layers would scarcely be noticed were it not for the behaviour of the weathered portion. The fresh rock is pink, but it usually becomes blue within distances of from one to four inches of a joint plane and brown in the last half-inch. In thin section (2492) the fresh rock from the dam quarry is seen to be made of quartz, microcline, microperthite and albite, and very little biotite ; the microperthite is made of microcline and a more highly refracting felspar. The texture is somewhat granulitic, but not sufficiently so to let the rock be classed amongst the acid granulites. Occasional thin strings of copper pyrites occur in the Rooi Berg gneiss, as in the granulites of Kenhardt Commonage. An epidotic gneiss from the west side of Rooi Berg (2490) consists of quartz, orthoclase, plagioclase and a microperthitic intergrowth of the two, epidote and very little biotite. This rock was taken from near one of the quartzite outcrops.

For considerable distance round Kenhardt all the granitic rocks are well foliated, but the hill called Zwart Kop on which the beacon common to Boven Rugzeer, Van Wyk's Pan and Gemsbok Bult stands is a massive, rather fine-grained granite, and there are ten similar kopjes on Gemsbok Bult's ground. The Zwart Kop rock seen in thin section (2364) is made of

parts are still fresh and are referable to labradorite; the augite is colourless and quite fresh; both these minerals often occur as crystals with slightly-rounded corners. As such fresh augite has not been met with in the lavas of the Wilgenhout Drift group, and as those lavas would seem to have been of a less basic nature than the rock whence the labradorite and augite of this tuff came, it seems likely that the latter really belongs to the Koras group and fills a fissure along the strike of the Wilgenhout Drift beds. The recognised basalts of the Koras group crop out within two miles of this tuff, and some thin dykes of a fresh-looking basic rock cut through the thick breccia described above.

Near the Groot Drink store (on the north-west corner of Stof Gat) there is a considerable thickness of fine-grained green rock, slightly banded at places, but without cleavage planes, invaded by the Groot Drink diabase, the non-porphyritic part of which it resembles rather closely, for both rocks weather spheroidally. When followed away from the intrusion the cleavage planes become pronounced. Two slices were cut from the green rock; one of them (2383) consists of small fragments of quartz and felspar in a greenish laminated matrix chiefly of indeterminate material with some calcite, chlorite and epidote; the other (2384) is a similar rock with more felspar, some magnetite and a few small fragments of devitrified lava having minute amygdales of chalcedony.

The narrow strip of green slaty rocks on Zwart Kop and Karos, overlain unconformably by the porphyritic rocks of the Koras series on the south-west and bounded on the north-east by faulted down conglomerates of the same series, can be assigned to the Wilgenhout Drift beds. They are micaceous grits and greenish slates, with very high northerly dips. There are rocks like them in the larger area on Karos, described below.

As explained on a previous page, the Wilgenhout Drift beds wrap round the north-west end of the Kaaien anticline on Karos (see p. 15), and the relationship seen there is of fundamental importance in fixing their stratigraphical position.

The bulk of the Wilgenhout Drift beds here are green slaty rocks, often with pulled-out amygdales. Some good exposures are to be seen round about the end of the Kaaien anticline. In these there are lying in the slates lenticles of unsheared lava several feet in length with distorted amygdales. A slice from one of these (2421) shows quartz

and epidote amygdales in a confused mixture of uralite, quartz and epidote.

The occurrence of a ferruginous impure limestone about 10 feet thick on a horizon 250 to 300 feet above the apparent base of the series, well seen on the north-east side of the Kaaien anticline is of intreest, because limestone in an analogous position occurs on Wilgenhout Drift.

The wide area between the quartzite anticline and the quartzites of the west side of Karos is a tract of gently-undulating ground with occasional outcrops of green slates and sheared lava. The rocks are poorly exposed, and some of them can be seen best in the bed of the Orange River at Baviaans Kranz, where, however, lavas were not found in the rather short space left uncovered by the water. The rocks seen in the river bed are sheared grits, greenish in colour, and some highly-sericitic beds.

In the south-western part of this area two masses of granitic gneiss traverse the slates, approximately parallel to the bedding and cleavage. The smaller of these is only about 200 yards wide and enters the Kaaien beds also; the larger is nearly a mile wide and does not cut through the latter.

The Wilgenhout Drift beds of this area are bounded on the south partly by a ridge of quartz-schist with parallel strike which projects into them but is separated from them on the north-east by the band of gneiss just mentioned, and partly by the sand-veld of the southern portion of Karos.

## THE GRANITE AND GNEISS.

Granite and gneiss cover a very large area in the Kenhardt district between the Orange River above Upington and the edge of the Karroo formation on the Bosch Bult. Their relation to the Kheis series suggests that the folding of the latter was accompanied by the intrusion of the granitic magma, for the foliation when present lies parallel to the strike of the sedimentary beds, and an examination of the gneiss makes it quite impossible to believe that the foliation was imposed upon an already solid rock. Such a process must leave conspicuous signs in the form of autoclastic structures, but the brecciated bands in the granite and gneiss are well defined narrow bands and do not cover wide areas.

There are many metamorphic rocks in the area that have been strongly folded and re-crystallised; these are the basic and acid granulites and the limestones of the Marydale series. Many of the basic granulites were certainly of volcanic origin, lava flows and intrusive sheets and dykes of basic composition. Though these are often seen to be made of minerals commonly

found in basic rocks of igneous origin, the relations of the minerals to one another are absolutely different to those in normal igneous rocks of similar composition. In the process of re-crystallisation the usual order of separation from the magma followed by the different minerals has not been observed; generally speaking, the anhedral grains of which the granulites are made have formed simultaneously, garnet being the only mineral which at all frequently shows crystal faces. In the granite and gneiss, on the contrary, the order of crystallisation of the minerals is usually normal. The acid granulites, several of which have been described on previous pages and in the Report for 1908, often have a mineral composition similar to that of the granites, and are undoubtedly re-crystallised rocks older than the granites of Kenhardt, but their original nature is obscure. Their separation in the field from the sedimentary schists and quartzites is difficult; and while it is easy to imagine that they are rocks of that kind impregnated with additional material from the granite magma which went to form the felspars, it is not easy to understand why a process, which has not greatly affected the limestones and basic igneous rocks invaded by the same magma, should have enriched the quartzites in felspar and other constituents. Some of these acid granulites can be regarded as altered sediments which contained felspar; but others, it seems, must be granulitised intrusive rocks of the composition of ordinary granites.

When granulitization can be seen in the gneiss of Kenhardt it affects the larger quartz and felspars partially or wholly, but the mica retains its original characters with the exception of the bending induced by pressure; the original felspars of the "eyes" in gneiss are converted into a mosaic of felspar without transference of material from the "eyes" themselves, which then have a fine-grained granular appearance in hand-specimens instead of presenting the usual large cleavages of the unchanged mineral. In a tract about two miles long on Vyf Beker this transformation is admirably exposed in all its stages, but the rock in the most advanced stage has still the same general appearance as the coarse augen-gneiss which evidently represents the former condition of the whole body of rock.

The question of the existence of granitic rocks in this area which are older than the Kheis series, and therefore much older than those which invade the latter, has not been decided. Their absence cannot be proved and would be difficult to explain. Possibly some of the acid granulites represent such

rocks. Up to the present time, however, the field work has not shown either that there is an unconformity between the acid granulites and any member of the Kheis series or that fragments of the granulites are enclosed in the latter.

There is another question unsettled, as to whether all the granitic and gneissose rocks belong to one and the same period of igneous activity. In this, as in all other great areas of such rocks there are veins of coarser and finer-grained material cutting through the usual types of rock, but such veins probably came from the same magma as the latter and were the result of a late phase of the one period of activity. The mere presence of granitic rocks both with and without parallel arrangement and banding does not give the desired evidence, for in many cases the massive variety forms patches within the gneiss, and the one grades into the other. By far the greater part of these rocks in Kenhardt is foliated, but the massive granite is more prone to appear in kopjes than the gneiss, on account of its greater power of resistance to the weather, hence many prominent outcrops are of massive granite, while almost all the rock between them is gneiss. In every case where the conditions admitted of investigation the massive granite graded into gneiss. In some instances, such as the Boks Puts well, where coarse granite with red orthoclase crystals occurs, the most striking massive varieties of granite could not be followed up.

It is impossible to sum up briefly the general characters of the granitic rocks of Kenhardt, for there are many varieties, and over wide areas outcrops are few and deeply weathered, so that it is difficult to recognise the precise nature of the underlying rock.

As a rule the area occupied by these rocks is one of very slight relief; it is gently-undulating ground of the kind called " the Bult " locally, and most of the ridges and hills in it are due to the presence of hard quartzites and other resistant rocks of the Kheis series. Towards the Hartebeest River, however, where there is better opportunity for the transport of soil and sand by water than elsewhere, there are more pronounced inequalities in the surface of the granitic rocks than elsewhere. The granitic hills which stand a long distance from the river are all made of less well-foliated rock than the surrounding gneiss, but traces of foliation are often to be seen in the hills themselves. Then, again, the pegmatites and masses of quartz, which appear to be of the same nature as the pegmatites, often give rise to small kopjes and occasionally to hills of considerable size, such as Brand Kop, on which one of the Angelier's Pan beacons stands.

In the south-eastern part of the granitic area, which includes the Brakbosch Poort Field-cornetcy of Prieska, there are very few granite outcrops, the rocks from wells and in the outcrops are distinctly foliated. The presence of gneiss and granite over such a large area is proved by the fresh cleavage fragments of orthoclase or microcline which cover the surface and are very conspicuous where the sand or soil contains coarse grit. Fragments of graphic granite are frequent; they are derived from veins and patches in the gneiss. Thin strips of dark rocks, either hornblende-schists or granulites are occasionally noticed in the gneiss. They are only a few feet wide and cannot be traced for more than a few yards; they resemble rocks described under the Marydale beds and are perhaps fragments of that formation. It is in this region, from Nels Poortje northwards, that the exposures of the Kaaien beds and the gneiss are frequently seen at such short distances apart that there is no room for the occurrence of a belt of Marydale beds along the western flank of the Kaaien beds. Another explanation of the strips of basic schists is that they may be altered dyke rocks. They do not appear to be the result of differentiation of the magma which solidified mainly in the form of the gneiss. Occasionally acid rocks of a very different character from that of the granite and gneiss are met with in similar masses. The origin of those rocks is doubtful; they resemble altered porphyries that have been regarded as acid lavas and described under the Marydale beds, but these thin dyke-like strips are isolated and so limited in extent that it is difficult to put them in the same group.

In the gneiss, about two miles west-south-west of Doonies Pan house there are narrow outcrops of an altered porphyritic rock which cannot be more than three feet wide; it must be a strip lying in the gneiss. It is a fine grained grey rock with rounded crystals of quartz and felspar. Under the microscope (2324) the matrix is seen to be a very fine grained hornfels-like mixture of quartz, greenish-brown biotite, garnet and magnetite; this encloses rounded pieces of quartz, felspars and sphene. At least two kinds of felspar, orthoclase and a plagioclase, form the rounded crystals looking like the corroded phenocrysts in quartz-porphyries. The orthoclase often encloses in poikilitic fashion rounded pieces of quartz and plagioclase, and also very many small elongated pieces of a more highly refracting colourless substance, probably a plagioclase; these small inclusions are distributed irregularly through the orthoclase, but almost all of them are elongated in the same direction. Rather large flakes of biotite are also enclosed

by the felspar. The grains of sphene are surrounded by a narrow zone of magnetite. There are also some grains of a deep green pleochroic mineral in the rock; it looks like a hornblende but wants the characteristic cleavages, and it has not been determined.

A very similar rock occurs on Put Zonder Water, in narrow bands, with rather coarse granite between them. In thin section (2331) one of the rounded felspars is seen to be microcline, and there is some apatite. In both these rocks there is a very faintly marked flow structure due to the disposition of the groundmass minerals. The rock associated with the Put Zonder Water porphyry has a coarser matrix of quartz-felspar and biotite, with well defined patches of micrographic intergrowth of quartz and felspar; there is very little magnetite (2330). There are small irregular crystals and rounded fragments of quartz, albite and microcline.

The northern beacon of Angeliers Pan stands on a rounded hill called Brand Kop, which has gentle slopes. The hill itself is a large mass of coarse pegmatite made of microcline and quartz, with a few scattered flakes of muscovite. The surrounding rock is biotite-gneiss, the foliation planes of which strike north-north-west, and biotite-garnet-gneiss with the same strike. As is always the case with the large pegmatites, the actual limit is difficult to find, owing to the quantity of fragments derived from the rock forming the higher part of the hill creeping down the slope and covering the boundary. The microcline crystals are of large size, for the loose blocks which lie in the soil are always parts of one individual so far as the microcline is concerned. In the hill east of Brand Kop great masses of white quartz are associated with the pegmatite.

To the west there are large areas of biotite gneiss with porphyritic orthoclase between Brand Kop and the Kombaers Brand well. On the rise north of the well, granite veins cut through the dark granulite described on page 29. This granite is poor in micas and white in colour; in thin section (2333) it is seen to consist of quartz, orthoclase, plagioclase of the oligoclase-andesine group, a very little muscovite, chlorite and blue tourmaline; the texture is of the granitic type.

To the north of the road, where it crosses the Kombaers Brand–Steyns Puts boundary, there is a remarkable mass of quartz and microcline in a coarse biotite-granite, with slight traces of foliation. Parts of the mass consist of microcline without quartz over many square yards, and single cleavage planes can be followed for many feet. There are wedge- or

origin is doubtful. The section (2352), cut perpendicular to the foliation, shows a fine-grained granulitic matrix of quartz, plagioclase, flakes of brown biotite, blue-green hornblende, and epidote, with streaks and lenticles of a coarser quartz mosaic practically free from other minerals. This may be an altered amygdaloidal lava of intermediate composition. The specimen was got from a well, and the rock does not form good exposures in the neighbourhood.

Between Van Wyk's Pan and Eiman's Holte there is much garnetiferous gneiss grading into granulite. The granulitic gneiss here is considerably coarser than the granulites of the Marydale beds. A section (2355) from an outcrop near the common boundary of the two farms and west of the road shows a coarse granulitic, partly granitic, mixture of quartz, orthoclase, albite, garnet, little biotite and muscovite, and a very little magnetite and apatite.

Three broad dykes of granitic gneiss occur in the Wilgenhout Drift beds; one is on Stof Gat and two on Karos. They are medium-grained rocks containing biotite, but the exposures are weathered and the only fresh-looking rock seen amongst them owes its fresh character to the fact that it has been crushed and recemented by silica, so that it is not a typical example of the intrusions. A section from this rock (2402), which is part of the Kruger's Puts (Stof Gat) dyke, shows that the felspars are orthoclase and microperthite; quartz, a little muscovite and chlorite and zircon are the remaining constituents. The weathered rock of this mass has orthoclase eyes, and is very similar to the larger mass in the Kaaien beds of Kalk Werf to the north-east.

Four masses of gneiss were noticed in the Kaaien beds along the Orange River, on Kalk Werf. The three smaller ones are narrow and follow the strike of the Kaaien beds, but the largest one, which is a continuation of the Zwem Kuil gneiss on the right bank, is in all over six miles long and traverses the Kaaien beds of Kalk Werf at an angle of about 30° with the bedding of the latter. This large mass contains inclusions of mica schist. The gneiss of Rooi Lye and Spitz Kop on the right bank of the river apparently is not continued on the left bank.

### *Diorites and Quartz-diorite.*

Closely associated with the granitic rocks of Kenhardt are some hornblendic rocks containing little or no quartz.

On the boundary between Van Wyks Pan and Eiman's Holte there is a rather coarse rock forming large outcrops

along a strip of ground about 30 yards wide amongst rather fine grained granulitic gneiss, and lying parallel to the banding of the latter. In thin section (2356) the texture is generally granitic, but some of the grains, especially those of diopside, have the granulitic shape. No quartz is seen in the section, the felspar is chiefly andesine, and there is much pale green hornblende (phochroism not strong, *x* greenish-yellow, *y* olive-green, *z* bluish-green); colourless diopside or augite, magnetite, apatite, epidote and chlorite are present in small quantities. The rock is slightly foliated, and it is probably therefore of about the same age as the gneiss and granite of the district.

A finer grained rock with more pronounced granulitic texture, but still not a typical granulite, forms a large mass south of the last mentioned outcrops. The constituents seen in the slice (2357) are oligoclase-andesine felspars, very pale greenish-blue hornblende, a little very pale bluish-green augite, a little quartz, apatite and sphene. The size of the grains is much less uniform than in the typical granulites, and their boundaries less regular and smooth; apatite is the only constituent which shows occasional crystal faces.

The usual types of pegmatite are not found in these dioritic gneisses, but their place seems to be taken by straggling veins of very coarse hornblende-felspar rock. Further to the south-west, on Mottels River, there are peculiar pegmatite veins of large biotite crystals and a little felspar traversing gneiss with streaks of hornblende-schist in it.

South of the western homestead on Steyns Puts there is a group of dioritic outcrops without noticeable foliation. In thin section (2336) the rock is seen to be made of andesine, brownish-green hornblende, apatite, calcite, epidote, and magnetite. The texture is granitic. The boundary of this mass of diorite seems to be indefinite, and the surrounding gneissose granite contains hornblende as well as biotite, so the diorite may be an extreme variety formed from the same magma as the granite.

### Dyke Rocks Older than the Karroo Formation.

Several dykes, which are probably older than the Karroo formation, were noticed amongst the ancient rocks of Kenhardt. The evidence as to their age depends upon their petrological characters only, as they were not seen in the neighbourhood of the Karroo beds nor were fragments of them identified in the Dwyka tillite. The contrast between the freshness of the Karroo dolerites and the altered conditions of the supposed older dykes of similar composition is marked,

and there can be little doubt as to the pre-Karroo age of those described below.

Some of the intrusions have been partly granulitized, and they must be older than the Karroo series, but there are cases in which no closer limits than post-Kheis and pre-Karroo can be set.

On Nrougas Nord there is a dark, very slightly schistose rock lying in the gneiss and forming a band about 30 feet wide, traceable for more than a mile parallel to a broad schist belt and the foliation of the gneiss. It is a greenish-grey fine-grained rock, with porphyritic plagioclase crystals as much as half-an-inch long. In thin section (2362) the large felspars are very cloudy, with the partial exception of a very thin zone at the periphery, which is clear, but the clearness is due to the granulitization of the felspar at the edge of the crystals, and the recrystallised mineral interlocks with the grains of the ground mass after the manner of the granulites. The small felspars are still partly preserved, but they are granulitized round a central cloudy portion, so that the original shape is destroyed. The rest of the matrix is a fine-grained mosaic of quartz and felspar in areas about .03 mm. wide (much smaller than the average grains of the usual granulites in the district), still smaller grains of iron ore, and larger grains and flakes of highly-coloured green hornblende, brown mica and very pale blue-green diopside or augite. The coloured minerals are to some extent aggregated in streaks and patches, and the hornblende forms the largest individual grains, which often enclose quartz and felspar. This rock is evidently a transition stage between a diabase-porphyrite and a granulite.

A remarkable granulite forms a dyke-shaped mass, 100 feet wide at the most, near the house on Boven Rugzeer. It is a massive rock (sp. gr. 3.18) without a trace of banding or schistosity. In thin section (2363) it is seen to have a granulitic texture, though the felspar forms larger areas than the other constituents. The felspar is labradorite and contains large numbers of rounded inclusions of a colourless mineral, with lower birefringence than the labradorite but having a higher refractive index, so that the smaller inclusions behave almost like isotropic bodies within the felspar, though the larger modify the tints between crossed nicols. The other constituents are very pale brown hornblende, diopside, olivine, deep green spinel, pyrites and magnetite. The hornblende is an unusual variety, and is pleochroic in pale yellowish-brown tones. The diopside is identified by the cleavages, extinction angles, and its positive character, but there are

other colourless grains which show rough parallel cleavages and straight extinction so frequently that they can scarcely all be orthopinacoidal sections of diopside, and they are very probably olivine. This is an exceptional type of rock and no other outcrops were seen, or rather identified with it, for in the hand-specimens the rock is not very different in appearance from other basic granulites without banding.

On the southern part of Zonder Pan some small dykes of diabase and diabase-porphyrite cut through the gneiss. They are dull blue in colour and are easily distinguishable in the field from dolerites of the Karroo type, one of which was found on the same farm. Under the microscope the porphyrite (2351) is seen to be much altered but not granulitized. The large felspars are replaced by a confused mixture made of sericite, epidote, uralitic hornblende, chlorite and a little quartz; the small felspars are usually replaced by a similar mixture of minerals, but an occasional fresh section can be found. Some augite is left in the remains of rather large crystals, but none is seen in the ground mass, which is made of grains and fibres of uralitic hornblende, epidote, quartz and magnetite.

On the northern part of Vaal Kopjes, rather more than a mile south-east of the hill made of cordierite rock, a peculiar dyke four feet wide runs E. 30° N. across the gneiss foliation. It is jointed in prismatic fashion perpendicularly to the walls. It looks rather like a Karroo dolerite in the hand-specimen, but in thin section (2419) it is seen to be quite different from that rock. The most conspicuous constituent is plagioclase, probably andesine, in long crystals with a peculiar brown colour due to extremely minute inclusions arranged in patches; portions of the felspar, usually a very narrow peripheral zone, are practically free from them and are in consequence colourless. The other constituents are tremolite and uralitic hornblende, magnetite, very small scales of biotite, and a little quartz, apparently an original mineral.

On Trooilaps Pan there is a large dyke of epidiorite cutting through biotite-gneiss. In section (2438) it is seen to consist of plagioclase, considerably altered, in lath-shaped crystals, uralitic hornblende with cores of colourless augite, a little quartz and micrographic intergrowth of quartz and orthoclase, brown mica, magnetite and apatite. It is quite a different type of rock from the dioritic masses of Styn's Puts and Eiman's Holte described on a previous page.

In the Wilgenhout Drift beds of Stof Gat, near their southern limit, there are two dykes of a rather coarse-grained rock of uncertain character. In thin section (2379) the chief con-

stituent is cloudy andesine, some quartz, apatite and magnetite are also original minerals, but the ferromagnesian mineral is replaced by chlorite in which there is no trace of the cleavage of the original mineral.

Another dyke on Stof Gat passes through both the Wilgenhout Drift beds and at least the lowest part of the Koras series. It is a coarse-grained rock with a fair amount of quartz (2396) ; both orthoclase and an acid plagioclase are present, but they are very cloudy ; quartz and orthoclase form a micrographic intergrowth ; both hornblende and augite are present ; the former is mostly altered to chlorite, and the latter has a marked development of basal striation or minute inclusions ; apatite, magnetite and sphene are also found in the slice. These rocks are probably all of later date than the basal conglomerates of the Koras series and may have been connected in their origin with the Koras lavas, to the acid and intermediate varieties of which they have points of resemblance.

A long dyke in the Kaaien beds of Zaals Kop (on the south-east corner of the farm) has followed the strike of the quartz-schists in the neighbourhood, though other similar dykes on Weg Draai and Uit Draai cut across the planes of schistosity. It may also be assigned to the Koras group, though it is rather less acid than the dykes mentioned above. It is made of much-altered plagioclase (2376), augite which is still largely fresh and has a tendency to form ophitic masses, a little quartz, magnetite, sphene, calcite and chlorite.

The only peridotite identified in the district forms a dyke on Drie Kop on the north side of a granulite belt and parallel to it. It was traced only 200 yards, and its width is about 40 yards. It is a heavy black rock made of olivine, diopside, serpentine derived from both of them, and irregular grains of green spinel and magnetite. The serpentine is pale yellow and has small grains of magnetite outlining former olivine crystals and in cracks, but the serpentine which is evidently derived from the diopside has no magnetite, though otherwise similar to the olivine serpentine. Magnetite also occurs in cracks in the spinel. It is evidently of the same nature as the rocks called wehrlite

## The Koras Series.

Certain volcanic rocks and sediments found on the right bank of the Orange River were described in the Report for 1907 under the name of the Koras series. The group was placed in the Ventersdorp system, though no satisfactory evidence could be put forward in proof; indeed, at that time there was no proof that the Koras series was older than the Karroo system. This latter point has been settled by the finding of boulders of characteristic Koras rocks in the Dwyka tillite between Verneuk Pan and Kruis Nord.

The age of the Koras series relatively to the Transvaal system and the Matsap series is still uncertain, though there is a very strong presumption that the Koras are the oldest rocks of the three; for the examination of the numerous outcrops of the Koras conglomerates on the left bank of the Orange River did not bring to light any pebbles from the Transvaal or Matsap groups.

The Koras group forms three distinct areas (see fig 7) in

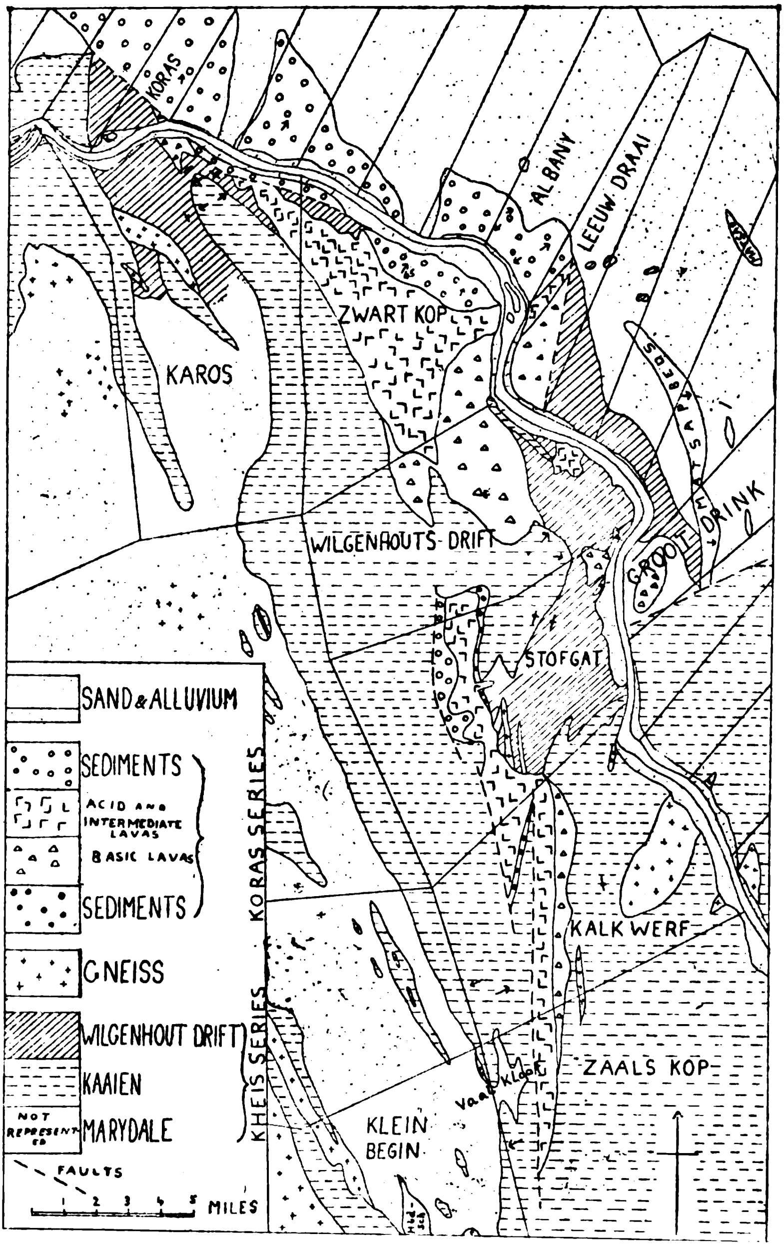



FIG. 7.—Country near Orange River above Upington. Both acid and basic lava areas include intrusions of a character similar to the lavas.

the left bank of the river in Kenhardt. The southernmost one extends from the middle of the western part of Zaals Kop, 17 miles northwards to the southern part of Wilgenhout Drift. It is narrow, and faults limit it on the western side for the greater part of its length, the lavas and conglomerates being thrown down against quartzites and schists of the Kaaien beds, while they rest unconformably on the Kaaien or Wilgenhout Drift beds, on the east (see fig. 8). The middle area is a small outlier lying on the Wilgenhout Drift beds on the eastern side of the farm of that name. The northernmost area stretches 19 miles in a north-westerly direction from Wilgenhout Drift to Karos, and is continuous with the Leeuw Draai–Rooi Kopjes mass of the right bank described in the Report for 1907. This area may in part be bounded by a fault on the south-west, but this point was not decided. An area of basic rock, an intrusion on Groot Drink[1] (north-east corner of Stof Gat) probably continuous with the intrusion on Groot Drink on the opposite bank, belongs to the Koras type.

[1] The farm names in this part of the district are rather confusing, as farms on the two sides of the river often have the same names. Thus Groot Drink is the name of a farm on the right bank but it is also the name of a well-known store and post office on the left bank. Koras is a farm on the right bank, spelt as here written on the divisional map of Gordonia; Karos is on the left bank, spelt thus on the Kenhardt map, though both names are pronounced similarly, but differently from the English or Dutch ways of pronouncing the written words.

E.

FIG. 8.—Section across the Koras series north of Ezel Fontein. Distance nearly 1¼ mile. Vertical to horizontal scale 2 : 1. K. Kaaien beds. Kg. Green schists in Kaaien beds. C1. Basal conglomerate of Koras group. D. Tuff and lava with amygdaloidal patches. P. Porphyry without amygdales. Pa. Porphyry with amygdales. C. Conglomerate with a band of sandstone, S.

In the Report for 1907[2] it was stated that the lowest rocks in the series are lavas, but on the north-western part of Stof Gat, near a water place called Ezel Fontein, there are conglomerates lying below the lavas, which are in their turn overlain by other conglomerates and sandstones. This lowest group of sedimentary rocks was followed for about four miles round the eastern flank of the lavas. These conglomerates have an arkose matrix, but the boulders and pebbles consist almost entirely of mica-schist, quartz-schist, quartzite and quartz, rarely of granite or gneiss; the boulders may be as much as 18 inches in diameter and are well rounded as a rule. The best outcrops are seen in a valley south-west of the middle beacon between Wilgenhout Drift and Stof Gat, where the rock has evidently been hardened by intrusions of blue diabase (see p. 81) related to the basic Koras lavas. The outcrops are large with smooth surfaces, and in places the outlines of the boulders are difficult to see. A thin section of the matrix (2389) examined under the microscope is seen to be made almost entirely of granitic *débris*. The larger grains are of quartz, felspars and micropegmatite; the quartz grains are often composite, as though they had been derived from a granulitised rock; the felspars are of four kinds, orthoclase, microcline, acid plagioclase and a microperthite. The small grains are fragments of the same minerals with the addition of a little muscovite, epidote, chlorite and magnetite. The cementing substance is mainly quartz, but a very little calcite is also present. The shape of the grains, large and small, is angular. Some of the quartz grains seen by the unaided eye are of the milky quartz.

In places the rock is deeply weathered and then has much the same appearance as rotten granite without foliation. Bedding planes were not seen.

The feature which distinguishes these basal conglomerates from those above the lavas is the absence of boulders of the latter rocks, which are very abundant in most outcrops of the higher conglomerates.

The basal conglomerates were again found to the north-west of Krugers Puts, a well on the western part of Kalk Werf, where they underlie the pophyritic lavas. They are not well exposed but appear to be wanting in boulders of the lava.

The thickness of these conglomerates is probably rather small, less than 50 feet, but their limits are always difficult to define on account of the covering of debris from the more resistant lavas and quartzites on either side of them. Their

[2] p. 53.

absence from the western side of the porphyries on Zwart Kop may, perhaps, be accounted for by the presence of a fault, but no definite evidence of the fault was found; on the northern part of Zwart Kop and the north-east part of Karos, where the amygdaloidal porphyry lies on slates belonging to the Wilgenhout Drift series, there is clear evidence of an unconformity in the shape of the line of junction, and there is no trace of a basal conglomerate here. These slates are bounded by a straight line on the north-east, a fault against which the sandstones and conglomerates of the upper group are thrown down. There is a small strip of blue diabase and diabase-breccia along the fault plane on Zwart Kop, the diabase and breccia outcrops were found to be about a mile in length and a few yards wide. The diabase resembles, in outward appearance, the blue diabase found elsewhere in the Koras series and described below. A thin section of breccia (2426) shows angular pieces of a once glassy rock which now has a greenish chloritic ground mass enclosing small crystals of felspar of the oligoclase-andesine series and a few green grains of uralitic hornblende, apparently replacing a pyroxene. The interstitial matter between the lava fragments is chiefly chalcedomy, epidote, chlorite, calcite, and a very little tremolite. An occasional piece of felspar is recognisable. The size of the lava fragments varies from an inch across downwards.

The igneous rocks of the Koras series are better exposed on the Kenhardt side of the river than in Gordonia, and from their character must be for the most part lava, though there are certainly intrusions very similar in nature to the lava. There is no constant order of occurrence; as noted above, amygdaloidal porphyry lies directly on the Wilgenhout Drift beds on Zwart Kop and Koras, while in the southern part of Zwart Kop there is a large area of blue amygdaloid which passes under the porphyry of the middle part of the farm; and on Kalk Werf the blue lava again lies below the porphyry.

The lavas are divisible into two groups, the porphyries, which are similar to the red quartz-porphyry of Leeuw Draai and Koras[1], and the diabases or basalts, which are related to the amygdaloidal lava of Leeuw Draai, Kameel Poort, and other farms in Gordonia[2], as well as to the intrusive rocks of Groot Drink, Leeuw Draai and Koras[3]. There is often great diffi-

[1]Ann. Rep. Geol. Com. for 1907, pp. 53-54.
[2]*Ibid.*, p. 54, 57.
[3]*Ibid.*, pp. 86-87.

culty in deciding whether some part of a large mass of either the porphyry or diabase is an intrusion or not.

Travelling northwards along the left bank of the river, the Koras series is first met with at the east end of the gap through the quartzite range called Vaal Kloof, on the western part of Zaals Kop. The Koras beds occupy the floor of a valley which lies nearly parallel to the hills on the east, but they are for the most part covered by red sand. Some large outcrops of amygdaloidal lava lie near the place where the road from the Kloof to Weg Draai leaves the road to Kalk Werf and other farms down the river. These outcrops are of a less acid type of rock than the porphyries on the same line of strike eight miles to the north, though they are evidently more acid than the blue diabase which lies below the latter rocks. Two thin sections (2403, 2404) were cut. The first, which is from a part with reddish matrix, though not so deeply coloured as that of much of the lava further north, explains the orgin of the haematite in the red lavas. The matrix is a usually translucent divitrified substance with many skeleton chains of magnetite, or magnetite mostly altered to haematite and with less sharply defined edges than the minute crystal-sections have in the less altered blue rock. The translucent part is yellowish in colour and made of indefinite aggregates of minerals with low refraction and birefringence. In this matrix lie numerous microlites and small crystals of oligoclase, often partly changed into a mixture of epidote, sericite and chalcedony or quartz, and granular augite of a brownish tint; some of the augite is in a slightly elongated prismatic form but it never reaches a well crystallised shape, nor does it ever enclose the felspar crystals. The amygdales are made of calcite chiefly, with some chalcedony, epidote, chlorite and an opaque iron stained substance without definite structure. The arrangement of the amygdales gives the rock a roughly banded structure due to flow. The second slice is from a blue lava with large amygdales of chalcedony and milky-blue quartz. There are no porphyritic constituents. The rock is more like some of the Pniel lavas than the Koras lavas generally are. The ground mass is made of an indefinite devitrified substance with granules and small crystals of fresh magnetite and small patches of chlorite. The very numerous small felspar crystals are considerably changed to sericite, epidote and chalcedony, but the fresh portions show that they are an acid variety. The augite is still fresh, and forms small elongated patches with a tendency to wrap the felspars, and also small crystals with prism and pinacoid faces,

Further north, on the western part of Kalk Werf, called Krugers Puts, there are two strips of Koras beds separated by a wedge of the Kaaien schists, and each is faulted on the west against the Kaaien beds. Though they are continuous on Stof Gat, the two strips are not made of the same rock; the western one consists of the basal conglomerate followed by porphyritic amygdaloidal lava, while the eastern one has apparently no conglomerate, but is made of an eastern portion, a blue diabase intrusion with large strips of amygdaloidal rock without crystalline constituents large enough to be visible to the unaided eye, and a western one made of red amygdaloid with occasional porphyritic and amygdaloidal lava. The distinction between the two parts is emphasized by the general blue colour of the eastern rocks and the red colour of the eastern, but numerous exposures along the streams which traverse the belt near its north end show that this distinction is purely a secondary one, and that the only real difference is caused by the presence of intrusive rock in the eastern part of the area. The separation of the intrusive rock from the lava is very difficult owing to the general similarity of the two and the nature of the ground, but that much of the rock is intrusive is proved by occasional contacts found in the area itself, and by a comparison of the supposed intrusive rock with dykes of the same material in the Wilgenhout Drift beds of Stof Gat.

In the stream beds referred to above there are all stages showing the transition from a blue, little altered rock, through red rock with epidote amygdales, to a very hard and brittle green rock containing an abundance of epidote throughout. This epidotised rock is always separated from the blue lava by a zone of red rock, and masses of it up to 15 feet in length have evidently been entirely surrounded by the red rock. The green rock resists the weather much better than either the red or the blue, and the red rock better than the but slightly altered blue lava, which is always found in a semi-decomposed state in the stream sections; though the blue frequently makes fresh outcrops at a little distance from the stream beds, in places where it is not kept damp so long after rain as in the immediate neighbourhood of the channels.

Occasionally small masses of sediment are seen to be enclosed by the lava, and these have undergone change to an extent corresponding to that shown by the enclosing lava. In one case observed on Kruger's Puts red lava encloses a mass of red jasper traversed by numerous small veins of chalcedony. The red jasper in this case is very like the red jasper frequently met with in the Ongeluk series of Hay and Bechuanaland.

A typical example of the doubtful rock on the eastern side of Kruger's Puts is a bluish-grey rock in which the only constituents visible to the naked eye are small spherical amygdales of a chloritic mineral scattered rather sparsely through it. In thin section (2401) there is seen to be a small quantity of a ground-mass, either of chlorite alone or a mixture of chlorite, magnetite, and some less well defined minerals which are evidently the result of devitrification of glass; this ground-mass is wedged between small felspars and augite. The magnetite is in small grains and crystals and also in very minute chains arranged as skeleton crystals. The felspar is fresh and is labradorite. The augite is also fresh, colourless and without basal striation; it forms grains and larger masses penetrated by the felspar, though the ophitic structure is not far advanced.

The lowest lava of the porphyritic amygdaloid belt on Kruger's Puts is a red rock of the andesitic type. In thin section (2400) the larger felspars are seen to be oligoclase with symmetrical extinction angles about twin planes up to 11°, while the minute crystals of felspar, which are very abundant, are of a more acid variety. There is no augite, but a few pseudomorphs of epidote and chlorite may represent that mineral which could only have been present in very small quantity. The ground-mass is a devitrified glass crowded with granules of red oxide of iron, often so thickly that it is opaque in the section. Calcite, epidote and chlorite, together with a very little chalcedony and stony, semi-opaque substance, fill the steam holes; these minerals also occur within the felspars and, to a small extent, in the ground-mass.

The porphyritic lavas of the type just described are intercalated with others which are like them but without the earlier generation of plagioclase. Two examples of these have been cut for the microscope (2397, 2398). The ground-mass is almost opaque with red iron oxides, and the grains and crystals of magnetite which probably furnished the iron have entirely disappeared. This matrix encloses innumerable minute felspar crystals which in their fresh state are oligoclase, but they are often replaced by chalcedony. There are no augites or pseudomorphs after that mineral. The amygdales are of epidote, chalcedony and calcite, written in the descending order of their relative abundance. Epidote and chalcedony also appear the in ground-mass, and their abundance in that position increases as the silicification of the felspar crystals does.

These lavas often include narrow, irregular bands of red stony matter of which the origin is rather obscure. They

simulate layers of steam-holes which have coalesced and have been filled with the dull structureless substance. They certainly differ greatly from the masses of sediment mentioned above.

These masses are often banded, and vary in colour from bluish, through red to green, with the enclosing lava. A thin section from one of them (2399) proves it to be made of small angular fragments (up to ·13 mm. in diameter) of quartz, acid plagioclase, microperthite, chlorite, white mica, chalcedony or chert, epidote, bluish hornblende, perhaps augite, zircon and sphene, set in a dusty and scanty chalcedonic matrix. It is evidently not volcanic ash related to the enclosing lavas, but a sediment akin to those that lie, as a whole, above and below the lavas of the Koras group.

The two strips of volcanic rocks become one on the Kalk Werf–Stof Gat boundary, but the red amygdaloid without porphyritic crystals disappears for some three miles, the only rock exposed at the surface being a porphyritic type, in which quartz crystals are present as well as felspar. The blue rocks appear only as rather narrow intrusions on the south part of Stof Gat, and they seem to be confined to the older rocks east of the Koras belt, the Wilgenhout Drift beds and granitic gneiss. Further north, near that part of Stof Gat called Ezel Fontein, the blue rocks form intrusions in the basal conglomerate and the amygdaloidal and porphyritic lavas, and there is a more varied succession exposed than in any other locality, although the total thickness is far less than on the right bank of the river or on Zwart Kop on the left bank (see fig. 8).

The intrusive rock has the effect of hardening the matrix of the basal conglomerate in its neighbourhood so that the pebbles cannot be broken out whole. It is a dark bluish, compact rock in which cleavage faces of felspar are visible with the aid of a lens. In thin section (2390) the ground-mass looks like a glass with very minute dusty inclusions in ordinary light, but between crossed Nicols it is seen to be devitrified, though the resultant crystalline matter is too finely divided for identification. The minute inclusions are iron ores and opaque brownish stuff; the magnetite occasionally makes small chains, but this skeleton arrangement is not well developed. The larger constituents are felspar and augite. The felspars are mostly fresh, though some are partly changed to a very fine-grained mixture of minerals with low birefringence; the largest crystals (.5 mm. long) are completely changed. The fresh felspars are simple individuals or once twinned, and are labradorite. The augite is occasionally bounded by prism and pinacoid faces but more often has

ragged edges; it sometimes encloses the ends of felspar crystals; it is often crowded with dusty inclusions arranged in planes parallel to the base; a partial change to chlorite is seen in many of the grains. There are a few small irregular cavities filled with chlorite and chalcedony, into which felspar crystals project. The rock is evidently closely related to the blue diabase and lava described on a previous page.

The lavas first met with (D in fig. 8) are dark blue rocks with many amygdaloidal bands and patches. In thin section (2391) one of these is seen to have a matrix which is almost opaque owing to the presence of presumably some sort of iron oxide, though it is neither in the form of magnetite or other metallic-looking mineral nor the red hydrous oxide which colours the rock further west. The matrix is partly made of chlorite and chalcedony. It contains small crystals and skeleton crystals of felspar, which is in part labradorite, but from the very numerous crystals which give low symmetrical extinction angles there must be a less basic plagioclase present. There is no augite visible, either fresh or replaced by other minerals. The amygdales are of calcite, chlorite and chalcedony, or a mixture of them.

With these lavas there are associated irregular bands of breccia and tuff in which the fragments of lava have undergone great change. They are greenish-grey rocks with an obvious fragmental structure. In thin section (2392) nothing is seen of the original characters save the outlines of the fragments and the steam holes; the original material is all replaced by epidote, chalcedony, calcite and chlorite, which occupy the place both of the larger fragments and the fine-grained interstitial dust.

In places, as represented in fig. 8, a thin band of conglomerate lies above these lavas and tuffs.

The lavas above this conglomerate are all of a less basic type than the blue lavas below. They are all porphyritic and reddish or grey in colour; but while some thick bands are amygdaloidal others have no amygdales.

A typical example of one of the non-amygdaloidal bands has a compact reddish, felsite-like matrix, with numerous but small crystals of felspar and quartz. It is in many respects like the rock from Leeuw Draai (1846) described on page 53 of the Report for 1907, but it is without the pegmatite crystals seen in that rock. Under the microscope (2393) it is seen to have a ground mass generally crowded with very small dusty particles, which are absent from short straight areas looking like felspar microlites in ordinary light; between crossed nicols the ground-mass breaks up into interlocking areas

of quartz, and the supposed microlites become dark or light in just the same manner as the area they happen to lie in. There is a fair amount of chlorite in a finely divided state in the ground-mass, and a little epidote also. Both the quartz and felspar crystals are deeply corroded. The quartz crystals are frequently cracked, and the two or more segments are shifted, so that they become dark at different positions of the Nicols. Round the quartz crystals a narrow zone of the quartz of the ground-mass is in crystallographic continuity with that of the crystal, and where the crystal is divided into segments each of these is edged by quartz continuous with it. The felspars reach a quarter of an inch in length. They are much altered to sericite, epidote, and chalcedony. They are occasionally fresh enough to show the carlsbad twinning, and these cases are apparently orthoclase. There are a few pseudomorphs of aggregates of epidote, chlorite and calcite after a pyroxene. Some magnetite, apatite and zircon are present.

The amygdaloidal porphyry is generally richer in felspar than quartz crystals. It resembles the non- amygdaloidal porphyry in colour and general appearance. In thin section (2395) the matrix is seen to be a microcrystalline mixture of quartz and felspar, with small patches of very minute and opaque or almost opaque needles; some epidote and calcite are present also. The felspar crystals are orthoclase and an acid plagioclase; both they and the quartz crystals are corroded. The amygdales are of chalcedony alone or chalcedony and epidote, rarely with chlorite in addition.

To the east of Ezel Fontein a dyke of quartz-porphyry traverses the greenish schists of the Kaaien or Wilgenhout Drift beds in a west-south-west direction; it apparently joins the porphyry near Ezel Fontein after traversing the basal conglomerates. It encloses pieces of a blue compact rock. The porphyry has a reddish matrix and numerous crystals of quartz and felspar, also a few amygdales. Most of the matrix is seen in thin section (2394) to be a micro-crystalline mixture of quartz and felspar, but there is some micro-pegmatite also, with a little magnetite, epidote and calcite. The quartz and felspars are corroded and the latter entirely replaced by sericite and chalcedony. The slice contains part of one of the compact blue inclusions, which is made of small crystals of an acid plagioclase set in an altered base containing magnetite, quartz, epidote and chlorite, apparently a piece of lava of a composition intermediate between that of the quartz-porphyry and the basaltic rock.

To the south-east of Ezel Fontein, the highest lavas seen

are red rocks with amygdales of quartz or chalcedony and epidote, but without crystals large enough to be visible to the unaided eye. These rocks are like those from Vaal Kloof and the andesites of Kameel Poort and Rooi Kopjes described in the Report for 1907.

Rocks of this type are also interbedded with the porphyry rather lower in the succession.

The highest beds belonging to the series in this area are red sandstones and conglomerates, like those on the right bank of the river described in the Report for 1907. A few thin bands of these rocks are interbedded with the lavas near their upper limit. The conglomerates contain pebbles of quartz, quartzite, quartz schist, sheared green slaty rocks and green amygdaloidal lava like that of the Wilgenhout Drift series, red porphyry and amygdaloidal lava from the lower beds of the Koras series.

This area of the Koras beds terminates northwards on Wilgenhout Drift against some high hills made of the Kaaien beds.

The northernmost area of the Koras group on the left bank of the river stretches from Wilgenhout Drift to Karos; on the south-west it is bounded by the Kaaien beds for the most part and by the Wilgenhout Drift beds for five miles at the north-west end. At the extreme south-east end the Wilgenhout Drift beds are again in contact with the Koras rocks for three miles, then the Kaaien beds, or quartzites supposed to belong to that group, lie between the Koras beds and the river for a mile; for some 16 miles the Koras beds reach the alluvium of the river or the river itself and are continuous with the Koras beds on the right bank.

The basal conglomerate in this area is apparently confined to a few very small outcrops on Karos, too small to be inserted in the map.

The porphyritic rocks are extensively developed on Zwart Kop, where they form hills rising 300 feet above the flat ground, they contain intercalations of purplish andesitic lava with epidote and chalcedony amygdales. These intercalations are seen on the western side of the lavas and also at the south-east corner, where the volcanic rocks reach the river. The porphyry is amygdaloidal in part, but there seems to be no distinction into an extrusive and intrusive body of rock. In the country on the right bank of the river some of the porphyry gives rise to kopjes made of immense rounded boulders,[1] but in Kenhardt, though the rock is of very much the

[1] Ann. Rep. Geol. Com. for 1907, p. 55.

same nature, it breaks up at the surface into small, more or less rectangular blocks, and thus makes hills very different in appearance from the Gordonia kopjes. The rock of the eastern part of the hills contains rather larger crystals of felspar than that of the western part. Two thin slices (2423 and 2424) from this porphyry area, one from behind Karos house and the second from high hills behind Zwart Kop house, show that the rocks are of the type described from Stof Gat on a previous page, but crystals of augite are present in the second slice. The ground-mass is the same in both, interlocking areas of quartz rendered cloudy by sericite and dusty inclusions with small clear streaks resembling microlites but made of the same individual as the area itself. Perhaps felspar may also be present in an unaltered state. The felspar crystals are very much altered, and are as deeply corroded as the quartz ; they are of orthoclase and an acid plagioclase. The augite is colourless and forms crystals up to 8 mm. in length, with corroded edges. In slice (2423) there are patches of green alteration products, chlorite and a serpentinous mineral, which probably represent augite. Magnetite, apatite and zircon are minor constituents. In some large masses of the porphyry a distinct flow-structure is seen, but this is not a general feature. On the river frontage of Wilgenhout Drift there is an isolated outlier of purplish-red amygdaloidal lava of the andesitic type without porphyritic crystals.

The blue basaltic or doleritic type of rock occurs at the north and south ends of the Koras series in this area, in each case it is a continuation of the rocks on the right bank described on page 86 of the Report for 1907.

The northern mass is the smaller ; it lies between the Koras sediments on the north-east and the Wilgenhout Drift beds on the south-west, but instead of forming a comparatively narrow mass as in Gordonia it is a wide body and sends at least one dyke south-eastwards into the Wilgenhout Drift beds. It is a blue rock with a few small amygdales of chalcedony and, in places, small dark crystals or pseudomorphs large enough to be seen on the outcrops. In thin section (2422) it shows a ground mass of a devitrified substance, which is often nearly opaque, containing altered and fresh felspar crystals of small size belonging to the andesine-oligoclase series, and grains of augite There are some pseudomorphs of chalcedony and sericite after felspar crystals as much as 3 mm. in length, but the slice does not include any of the dark pseudomorphs. From the field relationship of this rock it must be an intrusion.

The southern mass is much larger, being about six miles in

length and over four wide. It is continuous across the river with the intrusion along the fault on Leeuw Draai (page 86 of the 1907 Report). Though there are patches of amygdaloidal rock in this mass it seems to be an intrusion which made its way along the boundary fault between the volcanic rocks of the Koras group and the underlying Kheis beds. The river conceals a broad strip of ground, and the manner in which the Leeuw Draai fault terminates southwards has not been determined. The country occupied by the intrusion is almost divided into two by a northwards projection of the Kaaien schists on Wilgenhout Drift. The contrast in appearance between the low rough, dark-coloured, hills formed of the intrusive rock and the grey slopes of the hills made of the Kaaien belts is striking.

A thin slice of this intrusive rock on Zwart Kop (2425) has a cloudy devitrified matrix with some magnetite grains, which encloses felspar crystals of small size, in some cases of the labradorite-andesine series, but usually altered to a mixture of minute flakes and patches ; the augite is in grains and small patches enclosing the felspars. Another specimen from Wilgenhout Drift (2386) shows an advance towards a holocrystalline dolerite, though there is still a fair amount of devitrified ground-mass. The constituent minerals are the same as in the rock just described, but the felspars are larger on the average and the largest crystals have a tendency to form groups, so that they give rise to a glomero-porphyritic structure. The augite is in larger masses than in (2425) and encloses the small felspars. The larger felspars are entirely altered to an aggregate which consists to a considerable extent of sericite ; the smaller felspars are less altered in a similar way. The almost complete absence of calcite and epidote from these two sections is a remarkable feature.

These rocks can be called basalts, and they tend to grade into dolerite ; using those terms for originally glassy and holocrystalline rocks chiefly made of augite and labradorite.

A small intrusion of a similar rock lies close to the river and east of the narrow bar of Kaaien quartzite on Wilgenhout Drift.

A larger mass, entirely separated from the Wilgenhout Drift mass and lying in the Wilgenhout Drift beds, is seen round about the store called Groot Drink. It is continuous across the river with the Groot Drink inclusion described on page 86 of the 1907 Report. The rock weathers, in places, spheroidally and encloses large masses of the Wilgenhout Drift beds which have lost the usual cleavage through the effect of the intrusive rock. The colour of the two rocks is

the same, a deep bluish-black, and owing to the obliteration of the cleavage of the sedimentary rock and the fine grain of both, they are difficult to distinguish macroscopically. The igneous rock contains amygdales in places and also crystals of felspar large enough to be visible to the naked eye, but this is not always the case. A thin section (2385) from a rock near Groot Drink store consists of small crystals and microlites of andesine set in a devitrified matrix of chlorite, calcite, sphene and magnetite. Both in the hand-specimens and under the microscope this rock resembles a lava; it has amygdales of chlorite, calcite and chalcedony up to an inch in length; but it must be an intrusive rock, judging from its behaviour on the ground, where it sends numerous small veins into the Wilgenhout Drift beds, and neither bedding planes nor layers of breccia or tuff could be detected.

The sedimentary rocks of the highest beds in the Koras series are well exposed at intervals along nine miles of the river front on Karos and Zwart Kop. They cross the river into Gordonia, where they cover a wider area, described in the Report for 1907. They dip north-east at various angles up to 45°. The north-western part of these rocks is faulted on the south-west against the amygdaloidal and porphyritic lavas of the Koras series and also the Wilgenhout Drift beds, but the south-eastern part rests unconformably upon the lavas. From the disposition of the lavas and sediments there can be no doubt that the former vary greatly in thickness within short distances.

The sediments consist of sandstones and conglomerates. These two varieties are interbedded, and there is no definite order of succession. The sandstones are red gritty rocks occasionally false bedded but not usually so. They evidently contain much felspar and quartz. The conglomerates contain well rounded pebbles and boulders up to two feet long. The pebbles are often closely packed, and as a whole the rock has a distinct resemblance to the red conglomerates of the Uitenhage series in Oudtshoorn and Uitenhage. The pebbles, especially the quartzite pebbles, are frequently indented and occasionally fractured by pressure from neighbouring pebbles. The materials of which the pebbles and boulders are made are various; the most abundant rocks are varieties of porphyry, either amygdaloidal or compact, certainly derived from the underlying lavas; then comes the andesitic amygdaloids, all red or purple in colour, but pebbles of the blue basaltic and andesitic rocks were not seen; quartzites and vein quartz pebbles are abundant, and granite, gneiss, various schists, sheared

green amygdaloid, and red and black magnetic quartzites were found in some numbers. The sheared green rocks undoubtedly come from the Wilgenhout Drift beds. The red and black magnetic quartzites are like those described on page 42 of the 1907 Report, which were doubtfully referred to the Wilgenhout Drift beds.

There are many good exposures of these conglomerates and they were carefully searched for fragments from the Matsap beds, the Transvaal and Ventersdorp systems, and for typical basic granulites and hornblende-schists from the Marydale beds. None of these were found, but it was evident that all the rocks represented could have come from known outcrops from Gordonia, Kenhardt and Prieska west of the Langeberg and Ezel Rand. The conglomerates are of local origin. The absence of Matsap boulders is of importance, for the rocks of that series might be expected in a later conglomerate in the neighbourhood; but the absence of the Transvaal and Ventersdorp rocks is of less significance, because it might have been due to the intervention of the Langeberg range between the nearest area of those rocks and the Koras beds, on the supposition that the latter are of post-Matsap age.

The result of the examination of these rocks in Kenhardt leads to the suspicion that they belong to the Ventersdorp system, though the evidence is inconclusive. They are certainly of pre-Karroo age, very probably of pre-Matsap age. The doubt as to the stratigraphical position of the quartzites and phyllites of the Onder Plaats and Groot Drink ridges in Gordonia (page 24 of the 1907 Report) has not yet been removed. There are no rocks in Kenhardt, so far as the district has been examined, which can be referred to the same group, provided of course that the correlation with the Kaaien beds is found to be impossible, as it appears to be. The difficulties in the way of settling these questions are pointed out in the Report for 1907, and no solution can be expected until certain parts of Gordonia, not visited in 1907, have been examined.

## THE DWYKA SERIES.

This formation, consisting of the boulder beds overlain by shales, stretches in a west-north-westerly direction from the neighbourhood of Van Wyks Vlei in a belt averaging about 40 miles in width.

The northern boundary of the formation runs in a remarkably even manner from Smous Pan (Prieska) to Klaar Praat (Kenhardt); both the boulder beds and the granite and gneiss on which it rests form gently undulating country, often sand

covered and waterless. The weathering of the boulder beds gives rise to country thickly strewn with boulders of various rocks. The granite surface dips down at a low angle below the Dwyka, and the slope seems to be an original feature rather than due to a subsequent warping of the old land surface. The present boundary, therefore, is most likely due to the exposure of a pre-Dwyka or Dwyka feature, of no great magnitude however. The undulating form of the granite floor is proved by the structure of the country near the Hartebeest River. At Keel Afsnys Leegte numerous hummocks of granite project at various levels through the Dwyka, and these ridges usually have their longer axes coincident with the direction of foliation of the rocks, commonly nearly east and west in this neighbourhood.

On Lat Rivier, Zout Rivier, Modder Gat and De Kruis, where the older rocks have been deeply cut into by the Hartebeest River and its feeders the Zak and Olifants Vlei Rivers, the boulder beds cap an escarpment. West of the Zak River the Dwyka and gneiss both form undulating country.

The Olifants Vlei River has cut a channel ten miles long through the Dwyka down to the granite floor, measuring from the last outlier on the right bank on Modder Gat to the spot on Lange Kolk where the granite appears for the last time as one travels up stream. The Zak River, on the other hand, though it drains a very much larger area and presumably has a lower fall in this neighbourhood, only makes an indentation about 3 miles long in the Dwyka boundary. The difference is due to the slightly greater southerly slope of the Dwyka floor in the Zak River area, which is, at the same time, in a less favourable position for exposing the steepest part of the slope, assuming it to be a general south slope, than the Olifants Vlei River, as the latter runs nearly due north and the former north-east. The Zak exposes an inlier on Jagt Drift at the level of the valley floor, and three or four others at a slightly higher level. In the country lying in the fork of the two rivers several inliers of granite, gneiss and quartzite appear through the Dwyka, and the fall in the floor of the latter formation must be about 150 feet on either side of the middle west beacon of Lange Kolk, which stands on one of the inliers, within two and a half miles to the east and five to the west.

To the north of the main area small outliers of boulder beds are occasionally found, as on Wit Kopjes, but in several localities boulders of resistant rocks such as quartzite, chert, jasper, and banded ironstone, scattered over the surface of the sandy soil indicate that the Dwyka has only recently been denuded from the Bult. In the absence of wells or

good exposures, it is impossible to say whether the tillite still exists beneath the sandy soil on parts of the Bult. Large outliers occur on Merries Pan, Soft Sit, Kraan Vogel Pan, and farther to the north on Hartebeest Pan.

Owing to the nature of the country good sections showing the contacts of the tillite and the underlying rocks are rarely exposed, but on Keel Afsnys Leegte, where the road from Lekker Leg (Blaauw Puts) joins the main road from Carnarvon to Kenhardt, there is a poorly glaciated surface of gneiss showing striations running south 35° west, while on a little kopje, one and a half miles east of the main road on Zout Rivier, some striations run south 10° west. The Dwyka on the kopje is of an unusual character as it is composed of flaggy greenish material, like a flagstone but for the presence of numerous striated boulders of various sizes. These flags undulate and in places have been twisted up into sharp angles, sometimes to the vertical. Similar material, pinkish-grey, hard, very fine grained, but without boulders occurs a couple of miles to the south-west on the bult opposite the homestead on Lat Rivier; calcareous flagstones with small pebbles are found on Modder Gat. Tillite is found at Strant Berg extending from the low ground right up to the base of the dolerite capping the hill; at the junction the former has been baked into a hard rock. The tillite contains an abundance of calcareous matter, and in many places there are layers of calcareous rock several feet in thickness, showing bedding planes passing diagonally downwards across the bedding of the tillite; in places they may even be vertical. They recall the peculiar occurrences seen along the lower reaches of the Modder River in Herbert.[1] The boulder beds appear to be abnormally thick and irregularly developed at Strant Berg, for on the southern side of the hill the upper shales come in suddenly and at a much lower level, 150 feet further down the hill. The thickness of the boulder beds cannot be satisfactorily determined. At Viviers Pan a well is 110 feet deep in the tillite, but on account of the undulating nature of the country, it may well exceed 200 feet; the deep bore-hole at Dubblede Vlei (south-west of Van Wyks Vlei) gives approximately a thickness of 164 feet—but this certainly excludes the higher and finer-grained portions.

In the area enclosed by the fork of the Zak and Olifants Vlei Rivers the thickness of the tillite varies from about two feet to over 150 feet within three miles. Just south-west of the middle west beacon of Lange Kolk, which stands on

[1] Ann. Rept. for 1906, pp. 116-7.

an inlier of granite, etc., a very narrow band of tillite separates these old rocks from the nearest outcrops of the upper Dwyka shales. The presence of the tillite is proved by the pebbles and boulders covering the strip of ground referred to, which is flat and not more than 300 yards wide. The upper shales lie flat and at the same level as the south base of the exposed granite, which evidently slopes gently southwards. There is room here for only a very small thickness of tillite below the shales if the latter extended to the foot of the Kopje; possibly the shale rested directly on the granite. Very similar conditions prevail further west on the south side of two more granite inliers on Jagt Drift.

Within a mile of the southernmost granite outcrops along the Olifants Vlei River on Lange Kolk, there is a well sunk 36 feet into the tillite without reaching its base, and the top of the well is probably not more than 10 or 12 feet above the main valley floor, leaving a thickness of at least 25 feet of tillite below the level of the river bed.

The rocks occurring as boulders in the tillite vary from place to place, and to some extent also on succeeding horizons in the tillite at any one locality. Thus, at the foot of Strant Berg various diabases from the Pniel volcanic beds form probably 95 per cent. of the boulders, but higher up there is a fair sprinkling of granite, quartzite, chert and quartz-porphyry. In the area examined last year amygdaloidal lavas of the Pniel series are on the whole most abundant as boulders. A narrow zone characterized by a great abundance of small pebbles of chert, quartz, banded ironstones and brilliant red jaspers was traced from Springbok Pan to the west corner of Zondags Pan, a distance of fully 16 miles. The brilliant red jasper just referred to resembles closely the red jasper from the Ongeluk beds of Griqualand West and Bechuanaland, also some of that from the Kraaipan series; it is a very conspicuous rock, and it affords a ready means of detecting outliers of Dwyka tillite on the sand covered Bult north of the main outcrop. Where it is seen, further search generally brings to light boulders or pebbles of other rocks foreign to the immediate neighbourhood, and when some of these have the characteristic scratches on them the presence of an outlier is assured though it is often impossible to define its limits precisely or to estimate its thickness. Boulders of banded jaspers from the Lower Griqua Town beds are abundant in places, as to the north of Springbok Pan, and in the outlier north of Brand Kop, but they are very scarce in the neighbourhood of the Zak and Olifants Vlei Rivers; boulders of the Matsap quartzites are particularly abundant in the last

named area, and in the Hartebeest Pan and Brand Kop outliers. Ongeluk lavas are only recognisable by careful examination of a freshly broken boulder, so their distribution is not readily noticed, but they were found south of Kenhardt. Boulders of the Koras lavas and quartz-porphyries were found on De Kruis Zuid and Jagt Drift. Kaaien quartzites are not very abundant, and it is a striking feature in the composition of the boulders generally that transported rocks are far more abundant than local rocks.

The distribution of the various types of rock indicates that they have travelled south-south-west or south-west.

*The Upper Shales.*—Through decrease in the size and number of the inclusions in the tillite the latter passes upwards into shale. The passage from one to the other can generally be fixed with fair accuracy, and is at places quite sharp.

The shales in the lower part of the group are bluish in colour when fresh, but as seen cropping out on the low rises just south of the tillite belt they are greenish-buff, with a tinge of pink along a certain horizon. Some thin bands are very hard, almost quartzites, and dark in colour. Along the Olifants' Vlei River, and to the west of it, there are large pan-like surfaces cut in the middle portion of the shale group; Verneuk Pan is one of them.

Thin layers of fibrous limestone, usually black, are abundant in the middle and upper portions of the Upper Shales; ferruginous layers in which the iron occurs in layers of clay-ironstone, that give rise to ochreous bands on weathering, appear above the middle of the group. Fine exposures showing these ironstones and fibrous limestones are seen on Riet Kops Kolk.

The "white-band" due to the weathering of a carbonaceous shale at the top of the Upper Shales is a very conspicuous feature in parts of its course, especially where it forms the steep slope below the outcrop of a dolerite sheet. In appearance it is just like the white-band south of the Karroo, but no continuous layers of chert such as lie immediately above the white-weathering shales in the south were found in Kenhardt or Carnarvon, though flattish nodules of chert occasionally occur in the shales and just above them.

In this region the limit between the Upper Dwyke Shales and the Ecca beds has been drawn at the top of the white-weathering shales.

## THE ECCA AND BEAUFORT SERIES.

There is very little to add to the description given in last year's Report.

The Ecca remains a blue shale formation giving rise to

the flattish country intersected with low dolerite ridges stretching westwards from Van Wyks Vlei towards Brandvlei. Two thin zones of white-weathering shale (probably carbonaceous) are locally developed in it, one a short distance above the white band of the Dwyka on Schalkwyks Dam and Isaacs Kolk, and the second higher up on the northern side of Gannabosch Leegte on the Fraserburg-Carnarvon boundary.

The sandstones of the Beaufort beds appear north of Carnarvon town, where, penetrated by numerous sheets of dolerite, they give rise to the plateaux of the Karree Bergen, a very rugged tract of country cut into by numerous narrow valleys and producing some very striking scenery. A very prominent outlier of Beaufort sandstones and shales forms the towering mass known as Jagers Berg. It has no less than six sheets of dolerite, two in the Ecca shales and four in the overlying Beaufort beds ; none of the intrusions are of any considerable thickness however.

Fossils are apparently scarce in this region. *Glossopteris* leaves were seen in thin sandstones of the Beaufort beds on Kleederen Fontein in the Karree Bergen.

## THE KARROO DOLERITES.

The general habit of the Karroo dolerites in this area is much the same as that described in the last Annual Report. There is, for example, the same rarity of intrusions in the tract of granite and Kheis rocks ; the principal development of sheets towards the junction of the Dwyka and Ecca series ; the transgression of the sheets from lower to higher beds in a southerly direction ; the predominance of sheets in the shale formations ; and the abundance of narrow dykes in the sandstones of the Beaufort series. Many of these dykes are later than the sheets, which they cut.

The sheets themselves, more especially those which crumble on weathering, leaving great piles of dolerite rising from flats of yellow brown sandy material, are traversed by veins of light coloured rock, usually only a few inches in width, but in some places, on Houdenbek and Cyferwater for instance, several feet across.

These dykes, which show sharp junctions with the rotten dolerite, are rather irregular in habit and in places become amygdaloidal, containing small drusy cavities lined with small white crystals of felspar. They are very fine grained, light grey in colour and are characterised by peculiar darker patches which, by reason of their sharp boundaries and fine banding, greatly resemble inclusions of shale,but which prove to be really portions of the dyke matter of different texture

from the main mass. The dykes themselves show darker selvages and are not uncommonly well banded.

A thin section (2309) from one of these dykes on Cyfer water shows under a high power of the microscope areas of orthoclase felspar set in a ground-mass of quartz, plagioclase felspar, and an abundance of micaceous minerals in radiating tufts, along with some sphene and limonite.

A remarkable dyke, closely allied to these, is found traversing dolerite and shales ; it crosses the road on the western corner of Zwart Rand, giving rise to a marked "aar" owing to the growth of bushes along its course. The rock itself is not seen *in situ*, but fragments are found at a number of points ; it is coarse grained and can be termed a granite.

A thin section (2288) shows a very large amount of quartz, often in large areas possessing corroded outlines such as are found in the quartzes of quartz-porphyry. The felspar is mostly orthoclase and is slightly clouded owing to the formation of sericite, and there is a much smaller amount of a basic oligoclase present. The ground-mass is made up of an aggregate of prisms of orthoclase variously oriented and arranged sometimes in a somewhat radial manner as in spherulites. There are no ferromagnesian minerals, but limonite has separated out along the boundaries of the crystals, and with the limonite there is a little epidote.

These acid dykes represent a more acidic phase of the dolerite magma, and were injected during or immediately after the consolidation of the latter ; they are in turn followed and cut by dykes of basic rock.

Generally, most of the narrow vertical dolerite dykes in Victoria West and Carnarvon are a little later in age than the sheets.

In the extreme western corner of Zwart Rand a vein from 6 to 12 inches wide, of light acid material cutting through a sheet of coarse dolerite, is itself crossed by a dyke of dolerite from two to four feet wide, rudely jointed transversely in columnar fashion, very fine grained at the selvages and porphyritic in the centre. At the dam on Cyferwater a similar thing is seen and the rudely columnar dark fine-grained dolerite has, for the greater part of its course been intruded between the light coloured dyke and the coarse rotten dolerite.

At the eastern corner of the Carnarvon Commonage on the farm known as Lower Zwart Rand, there are eight small volcanic necks which seem to have been formed during the period of intrusion of the dolerites. They recall certain occurrences noted in Britstown,[1] but in this case the evidence of their volcanic nature is more conclusive.

[1] Ann. Rept. for 1908, p. 106.

The pipes are arranged in two rows of four each, the distance between the rows being a little over a mile (fig. 9); they make features on a very gentle, even slope of shale.

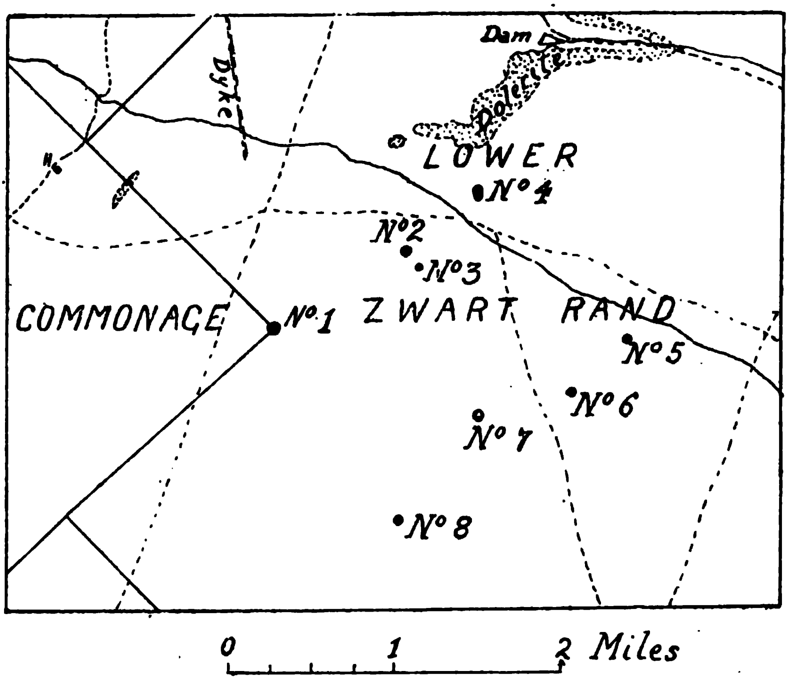



FIG. 9.—Plan showing positions of volcanic necks on Lower Zwart Rand, Carnarvon.

No. 1 rises to a height of about 50 feet and is at least 350 feet in diameter. It shows a massive greenish compact rock which is markedly vesicular in places, and exhibits fluxion structure. This banding is well seen on the slopes of the hillock, where it curves round to conform with the walls of the pipe and dips everywhere at a high angle, mostly towards the centre. Some of this banded fissile material can only with great difficulty be distinguished from highly altered flaggy shales which have been enveloped and metamorphosed by the igneous rock. Such masses are well seen on the north-west side where the bedding planes may be bent and broken, so that the rock almost becomes a volcanic breccia. The vesicles in the igneous rock may be filled with calcite.

No. 2 is very much like No. 1 and about the same in size.

No. 7 is about 300 feet across and shows in a very clear man-

ner a nearly vertical banding concentric to the outer wall of the pipe.

No. 6 is small and low, the outcrop being formed of a massive igneous rock which in places is very vesicular.

No. 4 is elongated and larger than No. 1, but otherwise like it.

No. 5 is not more than 300 feet across and contains only brecciated masses of bleached shales very much like the material at Grenaat Kop.[1] The stuff is intensely hard and contains small bi-pyramidal crystals of quartz and some iron ores lining cavities in the rock.

No. 3 is very small and contains brecciated shale alone.

A thin section (2307) of the rock in No. 1 proves it to be identical with the material composing the thin light coloured dykes which cut the dolerite sheets. It is very fine grained and shows numerous small idiomorphic crystals of fairly fresh orthoclase set in a ground-mass of plagioclase prisms, granular quartz, abundant tufts of micaceous minerals, and irregular areas of colourless sphene; there are some rectangular shaped serpentinous or chloritic pseudomorphs, while there is a fair amount of limonite in the ground-mass. A section (2308) of the rock in No. 7 shows similar characters.

The volcanic nature of these occurrences cannot be doubted, but, unlike the pipes filled with kimberlite, no inclusions of rock other than fragments of the adjoining shales were noticed in them. The extremely close petrological resemblances between the rock filling them and that forming dykes in the dolerites show that these occurrences must be regarded as a local and explosive phase of the igneous activity which gave rise to the great intrusions in the Karroo formation. Rock of a similar nature was found on the farm Biesjes Dam in the east of Carnarvon along the upper edge of a sill of coarse dolerite. It is greenish and mottled, and shows a streaky character with contorted banding, and in places is very difficult to distinguish from the adjoining shales. Other portions of this rock show micro-spherulitic structure.

In the ancient rocks of Kenhardt, north of the Dwyka boundary, the dolerites appear as dykes only. They are usually distinguished from the older basic dyke rocks without much difficulty owing to the fresh state of their felspars.

A dyke on the east side of the south end of Zonder Pan (2349) is a rather coarse ophitic dolerite without olivine. The labradorite and augite are quite fresh; the ophitic structure is not very well developed. There is a fair amount of green

[1] Ann. Rep. of Geol. Com. for 1908, p. 115.

hornblende but no biotite. The plagioclase is slightly zoned, and there is some interstitial micrographic intergrowth of quartz and untwinned felspar.

On the south part of Olyvenhout Drift a dolerite dyke lies parallel with the foliation planes of some mica-schist. In section (2412) it is seen to be an ophitic olivine dolerite with a very little red biotite ; the olivine is partly converted into serpentine.

## Dyke Rocks of Uncertain Age.

There are two dykes to the north-east of Gemsbok Bult house which are peculiar rocks. The shorter is only 300 or 400 yards long and has a north-west course, but the longer one was followed for two miles in a north 20° west direction from Gemsbok Bult on to Klip Kopjes ground. Two small outcrops of a similar looking rock were found in the northern corner of Gemsbok Bult, but whether they are of the same rock is unknown.

The long dyke is about 30 feet wide, and it is the only one from which a slice has been cut. Both this and the other rocks referred to above might well pass for dolerites of the Karroo type in the field, though they occasionally contain lenticular and angular fragments of quartz-felspar rock which may be inclusions of granite, a feature which is very rarely seen in the case of dolerite dykes.[1] Cleavage faces of felspar are visible to the naked eye, and also cleavages of a mineral which microscopic examination proves to be enstatite. Under the microscope the rock (2369) is seen to be porphyritic, the plagioclase, andesine and less basic varieties, occurs both in crystals nearly a tenth of an inch long and much smaller crystals in the ground-mass ; the enstatite forms crystals even slightly larger than the large andesines, but it does not occur in smaller forms ; the other constituents are green hornblende, biotite, micrographic intergrowth of quartz and untwined felspar, a little quartz besides that in the micropegmatite, magnetite, numerous very slight colourless hexagonal needles which are probably apatite, and opaque needles which may be rutile. The large and small plagioclase crystals are crowded with extremely minute black rods, but are quite fresh, as are all the other minerals ; the large felspar crystals are zoned, but the extinction angles do not vary from one zone to another, the banding disappears at the positions of extinction and at 45° to it between crossed Nicols. The large felspar sometimes

[1] Dolerite dykes in the granite under Hottentots Holland, near Sir Lowry's Pass and near Miller's Point, in the Peninsula, have been found to contain granite fragments.

penetrate the enstatite and they often contain small inclusions of the ground mass. The enstatite is distincly pleochroic; it is in every case surrounded by a narrow fringe of other minerals, usually green hornblende with red biotite in small flakes mixed with it often with a colourless mineral which is probably tremolite, rarely with a colourless mineral with very high extinction angles and high birefringence, probably augite, but transverse sections of this could not be found. Both the green hornblende and biotite occur in the ground mass, where the biotite very frequently coats the magnetite. The hornblende is never idiomorphic. The quartz and micropegmatite occur interstitially. On account of the remarkable freshness of this rock it cannot be looked upon as of pre-Karroo age, but it shows some resemblance to a dyke-rock in the Pniel quartzites of the Kimberley mine,[1] which was regarded as a pre-Karroo intrusion, though no proof of the age was obtained. The Kimberley rock contains less enstatite, which is almost colourless, and is more altered than the Kenhardt dyke.

The Kenhardt rock can be called an enstatite-porphyrite.

## Kimberlite and Allied Pipes and Fissures in Carnarvon and Victoria West.

Only a few pipes and fissures were met with in the area surveyed, but some interesting features were noted, while several inclusions of peculiar types of rock were obtained from them.

### I.—*Pipes and Fissures.*

On the farm Kaffir's Kraal (portion of Zwavel and Uijen Fontein) there is what seems to be a very small pipe rather than a fissure on the hill side at the extreme northerly spur of Beyers Berg. The inclusions consist of shale, dolerite, and some gabbros and granulites.

West of the homestead on Beyer's Fontein some prospecting pits have exposed kimberlite, probably a hardibank variety. Fragments of shale in it have been slightly hardened. Among the inclusions were biotite-gneiss, garnet granulites and eclogite.

In the eastern corner of Leij Fontein, 30 miles west-north-west from Victoria West, there is a large pipe which was first prospected about 18 years ago and which, like most of the older pipes, has been "re-discovered" from time to time.

The outline of the pipe, as shown in fig. 10, is irregular and is well defined, for the Beaufort sandstones and shales form a slight wall and dip away on all sides, especially to the south where the angle is considerable.

[1] Ann. Rep. Geol. Com. for 1906, p. 122.

The kimberlite is, for the most part, soft and has a rather darker colour than is usual ; this is due to the large amount of ilmenite contained in it ; at the southern end harder material has been proved by a shaft. With the exception of some fragments of yellowish sandstone and pinkish to purplish shales the inclusions are small and infrequent. On the east side there is a narrow fracture marked by a line, away from which the strata have been tilted at high angles and which is probably due to a dyke of kimberlite. It can be traced close to the boundary of the pipe but whether it actually unites with, or is cut off by, the latter is not clear ; certainly it does not cut it.

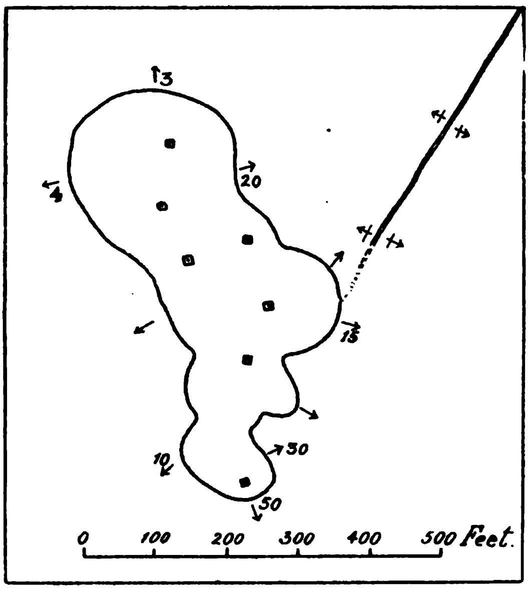



FIG. 10.—Plan of pipe on Leij Fontein, Victoria West ; the small squares represent prospecting shafts.

On the adjoining farm, Vrouwens Kuil, east of Leij Fontein, there is a long kimberlite dyke which forms a fine " aar " and which was followed for a distance of at least five miles in a southerly direction. It crosses at a very acute angle two parallel dolerite dykes which run close together. In a well cutting at the homestead the horizontal sandstones and shales have been tilted in a curve to the vertical within a distance of six feet on either side of the dyke. The dyke material is very decomposed but is a very micaceous variety of kimberlite.

On the extreme south-western boundary of the farm Riet Gat, nearly 20 miles west of Victoria West, there is a small pipe about 450 feet long and 200 feet across. Its southern extremity is well defined, for hard shales form a narrow ring and dip away at a high angle. The shaft in this portion shows hardish yellow ground with some fragments of very fresh hardibank, much like that of the St. Augustine's mine. The centre of the pipe appears to be occupied by a big mass of brecciated bluish shale which has been baked into a flinty material. The inclusions are small and consist principally of shale and dolerite, but there are a number of boulders of amygdaloidal basalt.

A very interesting dyke of lamprophyre was noticed in the south-eastern corner of the farm Carl's Graf (Carnarvon). It runs in a south-south-westerly direction past the base of the extraordinary hill known as the Jackals Toren and cuts through a dolerite capped hill to the south. A well section exposes a very narrow vein of lamprophyre with large micas, the rock being very much like that from Brak Kuilen, Britstown.[1]

II.—*Petrographical Description.*

2282. *Kimberlite.*—Pipe on Uintjes Berg, Carnarvon. [Ann. Rept. for 1908, p. 113]. This rock is a hardibank and shows the constituent minerals in a remarkably fresh condition although the specimen was taken from the surface. Olivine is present in quantity in the form of porphyritic crystals which, though much cracked, only occasionally show partial conversion into serpentine. A few large grains of enstatite have been changed into pale yellowish fibrous bastite. One large crystal of diopside is seen in this slice and shows the formation of calcite along the cleavage cracks ; with it occurs some magnetite. Mica is abundant, the ground-mass being full of extremely minute flakes. It is a pale yellow, almost colourless, variety, and often shows a stronger coloured border of the abnormal variety.

The most peculiar feature in this rock is the fact that the whole of the original ground-mass has been replaced by calcite, and this mineral surrounds the olivines, micas, etc., without penetrating, as a rule, along the cracks and cleavages of these minerals. In only a few places does the calcite appear to have been derived by direct alteration of one of the constituent minerals. There is an abundance of perofskite and magnetite.

2289. *Lamprophyre Dyke,* Carl's Graf.—This is a fine-grained rock with large plates of brown mica, it contains altered

---

[1] Ann. Rept. for 1908, p. 121.

olivines, one of them is more than three-quarters of an inch across. The thin section shows serpentine pseudomorphs after olivine, which occurs usually in grains but sometimes shows crystal edges. Yellow-brown mica is very abundant, it shows the usual tendency towards an exterior shell of a darker coloured abnormal variety; it is slightly bi-axial. The flakes are crowded with inclusions of serpentinised olivine, prisms of augite, grains of perofskite, etc., but the central paler parts of the plates are usually free from foreign matter. Augite occurs in numerous small prisms indefinitely terminated, sometimes penetrating the micas, sometimes moulded on them; it has a peculiar pale greyish-purple tint. Perofskite is abundant, while small spaces between the constituent minerals are occupied by calcite. Apatite seems to be absent.

2317. *Lamprophyre.*—Fragment in the pipe on Leij Fontein. Almost a pure mica rock, this mineral being pale in colour optically normal, and uniaxial. Very small rounded areas of green serpentine indicate the former presence of olivine. Rutile (sagenite) has developed from grains of ilmenite, while between the micas appear tiny areas of calcite.

2287. *Hornblende Eclogite.*—Inclusion, Uintjes Berg. Pink garnet with irregular outline; brownish hornblende; chrome diopside in slightly smaller amount than the hornblende; plagioclase, a basic variety, in aggregates; a good deal of ilmenite, large grains of rutile, and a little biotite. The specific gravity is 3.29.

2315. *Eclogite.*—Inclusion, Beyer's Fontein. In addition to garnet and diopside it contains a small amount of altered felspar, some ilmenite and a little rutile.

2314. *Pyroxene-granulite.* — Inclusion, Kaffir's Kraal. Abundant garnets, usually idiomorphic; predominant faint greenish pyroxene; clear plagioclase felspar. There is a small amount of hornblende either intergrown with the pyroxene or occurring along with biotite between the other minerals. There are some large grains of rutile, also some apatite.

2316. *Granulitic gabbro.*—Inclusion, Beyers Fontein. This rock shows characters rather like 2314, except that there is a good deal of altered hornblende while the structure only tends in a slight degree towards the granulitic.

2313. *Gabbro.*—Inclusion, Kaffir's Kraal. Large, irregular pink garnets with inclusions of the other constituents; a large amount of greenish hornblende, a few of the areas having small cores of greenish pyroxene. In places the hornblende is intergrown with plagioclase felspar, the latter being clear

and untwinned ; calcite is present as a decomposition product. Biotite occurs in fair amount, and there is some rutile.

2312. *Gabbro.*—Inclusion, Kaffir's Kraal. There is no garnet or pyroxene present in this rock ; the hornblende is pale green in colour, forming aggregates and also a very fine intergrowth with felspar which, inside the hornblende, has been usually replaced by calcite. Felspar is abundant, showing alteration to natrolite and calcite ; biotite is present in quantity, and there are large, irregular, colourless sphenes, some rutile and apatite.

These six rocks (2312—2317) form a series with gabbro at one extreme, and a typical eclogite at the other. By the appearance of garnet and pyroxene and the loss of hornblende and felspar, the gabbro passes into eclogite, the structure at the same time becoming granulitic.

A type linking the gabbros to the non-garnetiferous granulites is found in 2310, from Kaffirs Kraal. This contains a bluish-green hornblende in longish crystals and aggregates ; it is usually clear, but may have cores of a lighter-coloured amphibole, which is often so dusty as to be opaque ; it may possibly have been derived from pyroxene. The hornblende shows fine intergrowths with biotite, the latter being an important constituent. The plagioclase felspar is rather clouded, with formation of calcite ; there are some large apatites.

*On the inclusion within pipes of fragments of Basalt.*—The occurrence within the Smith-Weltevreden Mine of numerous fragments of vesicular basalt, forming in one place a coarse breccia, has been noted in the Report for 1906 (p. 146). Fragments of dark coloured amygdaloidal basalts have since been recognised in the pipes on Markt (Prieska), Uintjes Berg (Carnarvon) and Riet Gat (Victoria West), and probably this rock is more widely distributed, for the compacter varieties cannot be distinguished in the field from the inclusions of Karroo dolerite so abundant in the kimberlite. The basalts are dark in colour, almost black, usually amygdaloidal, and the vesicles are filled with zeolites, and are somewhat weathered, so that although the boulders are found as much as one or two feet in diameter, it is not always easy to procure fresh specimens. A section (2318) from an inclusion in the little pipe on Riet Gat shows the following features under the microscope ; the rock is medium-grained with numerous amygdales lined with green chlorite and filled with analcite, calcite and patches of radiating chlorite. Plagioclase felspar (andesine-labradorite) occurs in elongated crystals always of small size ; they show considerable alteration with the develop-

ment of calcite, chlorite, etc. Augite occurs in colourless granules or moulded upon the felspar ; there is a slight tendency to the ophitic structure. Olivine is absent. The groundmass of the rock is composed of darkish glass with much dusty matter and abundant minute octahedra of magnetite attached to one another and thus forming strings ; there are also large irregular grains of magnetite.

A rock from the pipe on Uintjes Berg shows (2286) similar characters. The plagioclase felspar is surrounded or flanked by augite. The base is a dark glass with a greenish tint, full of feather-like tufts and strings of magnetite crystals. The amygdales are lined with yellowish chlorite and filled with calcite, analcite and other zeolites.

A coarser variety (2285) from the same pipe is a rock with fairly well developed ophitic structure, but there are patches of altered brown glass containing magnetite crystals between the other minerals. The felspar is labradorite, and the larger crystals show zoning. The augite is colourless, but may show the diallagic structure ; some of it has a little green aegirine fringing the ends of the crystals, probably a secondary mineral. There are patches of greenish-brown chloritic material occupying what appear to have been drusy cavities into which the felspars project. In their shape they resemble the glass patches, but the absence of any objects representing the chains of magnetite crystals in the original glass prevents their being regarded as devitrified glass.

Petrologically these basalts have the closest resemblance to the Drakensberg lavas, and they are quite different from the lavas of the Pniel and Kuip series, though they have a decided resemblance to some of the lavas and intrusions of the Koras series. Their low density distinguishes them from the Karroo dolerites. It is very unlikely that they are pieces torn off an underlying pre-Karroo volcanic series.

Of late years it has been shown that volcanic rocks of the Drakensberg type, and probably belonging to the same age as the lavas of Basutoland, etc., have a very wide distribution, since they have been found in the Central Transvaal, Zululand, the Northern Kalahari and Rhodesia, and Nyassaland, possibly also in German South-West Africa. In view of these discoveries it would not be surprising to find evidence of the former existence of an area of Drakensberg lavas in the district under consideration, and possibly these fragments have been preserved in the later pipes just as fossils from the Ecca and Beaufort beds (*Chelyoposaurus*, etc.) have been preserved in the pipe of the Wesselton Mine, though the strata from which

they came have long since been removed from the district by denudation.

## Superficial Deposits.

The soil over the ancient rocks of Kenhardt is thin as a rule and cleavage fragments of felspars are very abundant in it; over some areas one notices the reflection of light from these cleavage faces, as one rides along, and this indicates the positions of pegmatites, for where outcrops of the pegmatites occur they are always surrounded by conspicuous cleavage fragments of felspar.

The soil in the valleys is naturally thicker than that on the bults, but it is only in the larger valleys of the Orange, Hartebeest, Olifants Vlei and Zak Rivers that the alluvial ground becomes conspicuous.

*Alluvium.*—The alluvium of the Orange River forms a strip of ground of varying widths on the left bank in Kenhardt. Comparatively little use is made of it, because its average level is too high above the river in normal circumstances to allow of irrigation without pumps, or without making a long channel to take water from the river at a spot far above the ground to be cultivated.

An examination was made of the irregular banks of alluvium being exposed by the fall of the river on the farms Matjes River and Karos. The upper surface is smooth and gently rounded, and the sides are marked by a series of parallel miniature terraces due to the erosion performed by the small waves on windy days as the water level fell. Occasionally a nearly vertical section, one or two feet high, had been cut in a bank by water and wind combined, and these sections lay bare the internal structure. The material is fairly uniform throughout the part exposed, with the exception of very thin dark layers apparently due to vegetable matter mingled with the yellowish silt. These layers bring out the false bedding of the silt admirably. The dip of the laminae is down-stream for the most part, and at varying angles according to the direction in which the section happens to cut the broad and low half-cone shaped groups of laminae. The appearances seen in these banks are precisely like the false bedding in the dry silt at various heights above the river.

The Hartebeest River, formed by the confluence of the Zak and Olifants Vlei Rivers above Kenhardt, was only examined as far down as some 20 miles below that town; the alluvial patches below the junction of the two rivers are very much smaller than those in the separate valleys above, and apparently much thinner. They are found behind the

larger bands of granulite and schists, which are more resistant rocks than the gneiss and granite ; a good example is seen in the Modder Gat alluvium behind the granulite belt which crosses the river at the lower end of the farm, and another is seen behind the next belt on Wit Klip and Zwart Puts. The larger tributaries are also instrumental in bringing about the formation of a flat and the consequent deposition of alluvium where they join the main valley.

A transverse section across the Hartebeest valley has steep slopes compared with similar sections across the Zak or Olifants Vlei valleys on the Dwyka formation. There is a marked difference in this respect between the valleys lying in the ancient rocks of Kenhardt and those in the Dwyka tillite, but in the Upper Shales the valleys become flatter still, and the river itself has no longer a definite bed, but in flood times spreads over miles of country and deposits a more or less uniformly thin layer of silt.

The alluvium is thickest, judging from the scarcity of outcrops of the underlying rocks, in the valleys of the Zak and Olifants Vlei Rivers, which are covered with a fairly uniform growth of low bush, but in the smaller valleys, such as those of Hartogs Kloof and the Zwart Kop stream, there is a great development of pans or "vloers," flat bare surfaces, chiefly sandy mud but partly crumbly shale and fibrous limestone outcrops. These pans are probably not depressions with no outlets but very flat surfaces with a slight fall towards the outlets, *i.e.*, down the valleys of which they form a part. The sandy mud in them contains small gypsum crystals and more or less common salt, probably also other salts. Bush will not grow all over them, and the limits between the pan and surrounding veld is quite indefinite. A section on Verneuk Pan, the largest (rather over 100 square miles in area) pan of this kind in the district surveyed last year, showed three inches of sandy mud mixed with small crystals of gypsum lying in a layer of gypsum one quarter of an inch thick, and below this flat-lying shales and thin limestone of the Upper Dwyka shales.

The reason why the alluvium of the larger rivers supports a continuous cover of bush, while that of the pan surfaces in the smaller valleys does not do so, is apparently that the soil is less brak ; and the difference in brakness is probably due to the occasional floods which wash out much of the salt from the larger valleys while the smaller ones very rarely receive enough rain to cause the rivers to run through their length, so that the soluble salts accumulate in the small valleys only.

*Sand.*—The soil is sandy through the large part of the Kenhardt district which lies north of the Karroo formation, but the sand is sufficiently abundant to cover all evidence of the nature of the underlying rocks in more restricted areas. The chief sand area lies immediately west of the northern part of the long range of hills made of the Kaaien beds. From Zonder Pan north-north-westwards thick sand stretches continuously for a distance of some 55 miles, varying greatly in width but having a maximum width of 13 miles on Koegrabe. There are large outlying patches west and south-west of Koegrabe, between the quartzite hills. The sand has a gently undulating or flat surface for the most part, and only rises into dunes along the base of the hills and on Koegrabe. The dunes near the hills lie parallel to the trend of the hills, *i.e.*, about north-north-west, but on Koegrabe there is a group of dunes about 10 miles long with north-west or north-north-west course, the usual directions taken by dunes in Kenhardt when they are not near a hill or river. The sand belt comes to an end within three miles of the Orange River, the left bank of which is practically free from sand throughout this district, though dunes reach the right bank at several places.

On the right bank of the Hartebeest river an interrupted line of dunes flanks the river for some fifteen miles below Kenhardt, keeping parallel to it.

Of the isolated dune areas the most important is that of Zand Ruggens and Klip Bakken, fifteen miles long and three wide at the widest part, but there are two large inliers of rock in this belt, which trends west 30° north. A smaller belt on Klip Bakken and Ratel Draai is six miles long and about half a mile wide ; it lies west 30° north.

A large belt which starts on Riet Fontein and is divided by the prominent schist band of Eksteens Kuil into two branches has not been followed to its north-west end, but it must extend to within a few miles of the Orange River.

The sand dunes of the Olifants Vlei River referred to in last year's Report were found to terminate to the north-west on Thys-Zyn-Dam. At Breek Kerrie, where the belt attains a width of three miles, a branch strikes westwards, then bends south past Bril-Zyn-Dam returning to its westerly course just south of Koker Berg. It follows, therefore, and at a distance of a few miles, the course of the dolerite escarpment lying to the south. This peculiar double bend in the belt is shared as well by the dunes, for in the neighbourhood of Bril-Zyn-Dam they lie with their long axes approximately north and south. It is probable that the orientation of the dunes, and therefore of the course of the belt, is due to the deflection

of the north-westerly wind along the face of the dolerite-capped ridges of Schiet Kloof and Gougo. The dunes are built of bright red sand and in places attain a height of 40 feet.

Red sand with small dunes occurs to the south-west of Van Wyks Vlei on Vissers Kloof and Blaauw Poort.

*Surface limestones.*—Throughout the Kenhardt district tufaceous limestone is frequently met with, except in the neighbourhood of the Hartebeest and Zak Rivers.

On the hills made of the Kaaien quartzites the calcareous tufa is practically absent; it only occurs on these rocks where they have been reduced nearly to the level of the surrounding country or are partly covered by the Dwyka tillite, as in the neighbourhood of Nels Poortje. Along the Orange River there are patches on both the Kheis and the Koras formations.

The granite, gneiss and schist country between the Hartebeest River and the Kaaien hills bears innumerable small patches of tufa, but it becomes thick only in some of the valleys, and there were nowhere seen such continuous sheets of the rock as are met with in Griqualand West and Bechuanaland.

The thickest limestone seen in the district is seen in the banks of the river bed which passes through Kalk Gat, a part of Ratel Draai. The bed rock is granite, exposed at places below the limestone, which is eight feet thick in some spots but usually rather thinner. The base of the limestone contains much grit and angular fragments of granite, but no water-worn pebbles. The limestone above this gritty layer is rather clayey and contains numerous small shells belonging to the genera *Planorbis* and *Physa*, but no shells of the large *Unio* which occurs in the Zak River and in the alluvium of that and other rivers in the north of the Colony.[1] The uppermost layer, from six inches to two feet thick, is harder than the limestone below, and also contains shells of the same kinds. In part of the section a layer, two inches thick, of dark vegetable matter mixed with much sand and a little limestone lies between the hard rock at the top and the softer limestone below. Though more rain than usual fell in the Kenhardt district last year, there were no pools in this river in July, and the abundance of the fresh-water shells points to a time when there were more or less permanent pools at this locality. Whether the present lack of them is due to a change of climate, or to the cutting down of the river bed since the country was

[1] Large specimens were found in the Ongers River alluvium, where a dam was being made on the Smartt Syndicate's property. The shells were sent up by the Director of Irrigation, Mr. F. E. Kanthack.

first occupied by farmers with much livestock, is not easy to decide. That the limestone was formed in a local pool is very probable, because similar banks of limestone were not seen above or below the Kalk Gat locality, and there was nothing to indicate the continuous flow of water in former days, in fact the absence of rolled pebbles from this and similar valleys shows that if water ever ran down them more or less permanently that period was very remote from the present time.

As a rule the area occupied by the Dwyka tillite is characterised by the presence of much surface limestone and this is the case with the tillite area east of the Olifants' Vlei River, but the immediate neighbourhood of the Hartebeest, and of the Zak and Olifants' Vlei Rivers near their junction, is remarkably free from it. No surface limestone was met with in the tillite area between those two rivers, nor on the very flat ground occupied by Verneuk Pan and similar features on the Upper Dwyka Shales. The explanation of this fact is not obvious, for, considering that the brakness and abundance of gypsum in the flat country show that much more water escapes by evaporation than by surface drainage, one would expect tufaceous deposits to be particularly abundant.

Along the Olifant's Vlei River above Verneuk Pan there are nodules of limestone in the soil, and occasionally larger deposits.

*Gravels.*—Gravel is remarkably scarce throughout the district. Along the Orange River no gravel deposits of noteworthy size were met with; the covering of more or less angular *debris* washed down from the hills on to the flatter ground near the river is not typical gravel, though rolled fragments of rocks foreign to the district, *e.g.* pieces of the Lower Griqua Town beds are found with this locally derived material in places.

On the Dwyka tillite the surface of the ground is usually strewn with boulders and pebbles, but these have been weathered out from the tillite and they have not been a source of gravel along the Hartebeest River. No gravels were seen on the Hartebeest River or its tributaries, though the tillite has furnished pebbles which cover a low terrace at some distance from the Olifant's Vlei River and on its right bank.

THE

# ZWARTKOPS BORE-HOLE.

---

BY

A. W. ROGERS.

# THE ZWARTKOPS BORE-HOLE.

By A. W. Rogers.

The deep bore-hole put down on the flat ground on the right bank of Zwartkops River by a Port Elizabeth Syndicate reached the depth of 3,630 feet without entering the Palæozoic rocks which probably underlie the Uitenhage series at that place. A visit was made to Port Elizabeth shortly before the work was stopped for the purpose of seeing the samples of rock preserved from various depths. Owing to the use of a percussion drill, which was evidently well adapted for the purpose, the rocks were brought up in a powdered state generally, though some remarkably large pieces were occasionally recovered.

Owing to the kindness of the Syndicate, and especially of Mr. G. W. Smith, I was able to examine all the material preserved and to send several pieces of fossiliferous rock to Dr. F. L. Kitchin, of H.M. Geological Survey, who has made a detailed study of the fauna of the Uitenhage series. Dr. Kitchin kindly examined the fossils and sent a preliminary account of their significance, but he hopes to be able to make more definite determinations.

The following is a summary of the nature of the rock brought up from the depths noted, based on the specimens in the keeping of Mr. G. W. Smith in October, 1909. The top of the bore-hole is about 20 feet above sea level.

25 ft. Slightly calcareous sandstone with fragments of shells.

48 ,, Quartz sand with shell fragments.

69 ,, Quartz sand with specimens of *Nassa kraussiana* Dunker, a species which lives on the South African coast and is found also in the raised beach deposits of the Port Elizabeth neighbourhood,[1] in the estuarine sands of the rivers in the Knysna district,[2] and in the raised beach of Klein Brak River.[3]

[1] Schwarz, The Pleistocene deposits of Port Elizabeth, Trans. S.A. Geol. Soc., vol. xii., 1909, p. 115.

[2] Ann. Rep. Geol. Com. for 1899, p. 61.

[3] Ann. Rep. Geol. Com. for 1905, p. 293.

Between 69 ft. and 82 ft. the bore entered the Uitenhage beds.
82 ft.—270 ft. Blue sandy clay with small pebbles of quartz and quartzite.

276 ft. Blue clay with small indeterminable gasteropods.
286 „ Red and greenish clay with small soft sub-angular slate pebbles.
300 „ Red and green mottled clay.
400 „ Soft red clay.
450 „ Red and green mottled clay.
500 „ Reddish-brown clay with some gritty material.
590 „ Red and green mottled clay.
618 „ Red clay.
620 „ Whitish-red clay.
700 „ Red and green mottled clay, with small sandy lumps.
720 „ Red and green clay.
790 „ Dull red and green mottled clay.
803 „ to 819 ft. Loose yellowish sandstone with a few indeterminable shell fragments.
855 „ Red and green mottled clay.
878 „ Red and green mottled clay.
900 „ Piece of brown ferruginous, loosely-cemented sandstone.
910 „ Pale red, greenish and white clay.
924 „ Reddish-brown clay.
960 „ Grey-green sandy clay.
1000 „ Red and green mottled clay.
1100 „ Red clay.
1110 „ Red and green mottled clay, rather sandy.
1133 „ Red and green mottled clay.
1150 „ Brownish-red clay.
1236 „ Green and red mottled clay.
1272 „ Red clay.
1320 „ Red and greenish clay.
1350 „ Red clay.
1358 „ Red and green mottled clay.
1360 „ Red and greenish clay with a streak of red sandy rock.
1426 „ to 1430 ft. Blue clayey shale with fossils. Dr. Kitchin writes of this: " *Modiola* sp. [Ornate; probably new species]."
1480 „ Red clay.
1500 „ Greenish clay, slightly gritty.
1625 „ Greenish sandy clay and red clay.
1627 „ Green and grey sandy clay with grit in a few fragments.

1650 ft. Grey sandy clay, some pieces are more sandy than others. Called sandstone in the journal of the bore-hole.

1740 „ Brownish sandy clay.
1800 „ Green and brownish-red clay.
1810 „ Brown and grey clay.
1825 „ Greenish, grey and brownish clay.
1840 „ Grey clay.
1860 „ Grey clay with nodules of pyrites.
1880 „ Grey clay.
1895 „ Grey clayey shale.
1900 „ Sandy clay.
1920 „ Greenish clay with some grit.
1935 „ Red and green mottled clay. Dull brownish-red in part.
2000 „ Red and green mottled clay, gritty in part.
2040 „ Grey sandy clay.
2050 „ Grey shale with fragments of indeterminable lamellibranchs.
2076 „ Grey clay.
2090 „ Grey clay.
2100 „ Grey clayey shale with small shells, of which Dr. Kitchin writes " *Cyrena ?* and Cyprids ? "
2140 „ Grey clayey shale with shells, of which some are *Melania* and others crushed lamellibranchs.

2190 „ Sandy clay and clayey shale with fossils, of which Dr. Kitchin writes: " Gasteropod, indet. [with high body-whort and elevated spire; possibly *Limnœa* or an allied form]."

2260 „ Blue-grey clay with shell fragments.
2312 „ Grey clay.
2335 „ Grey clayey shale with shells, of which Dr. Kitchin writes: " Crushed lamellibranchs, perhaps *Cyrena*. Also *Viviparus* (= *Paludina* auctt.) [very poor specimen, but probably *Viviparus*]."

2400 „ Grey clay.
2444 „ Slightly sandy clay.
2500 „ Clayey shale with fossils, of which Dr. Kitchin writes: " Crowded with Cyprids; probably *Cypris* or *Cypridia*."
2535 „ Slightly sandy grey clay.
2600 „ Clayey shale with fossils, of which Dr. Kitchin writes: " *Modiola* sp. [unornamented]; *Melania* sp.
2625 „ Grey shaly clay.

2670 tf. Grey clayey shale with fossils, of which Dr. Kitchin writes: "Fragments of *Modiola* and other lamellibranchs. *Bythinia* or perhaps *Viviparus*, with depressed spire."
2710 ,, Grey clayey shale with crushed lamellibranchs.
2753 ,, Grey clay.
2795 ,, Grey sandy shale with bits of ironstained and cemented shale. Fragments of shells.
2825 ,, Grey clay.
2850 ,, Grey clay.
2866 ,, Grey clayey shale.
2948 ,, Grey clay.
3023 ,, Grey clayey shale with fragments of shells.
3135 ,, Dark grey clayey shale.
3150 ,, Broken shale and quartz sand.
3233 ,, Quartz sand and grey shale fragments.
3245 ,, Grey fine sand and bits of shale.
3267 ,, Loose whitish sandstone and sand.
3380 ,, Coarse yellowish sand.
3400 ,, Coarse yellowish sand.
3430 ,, Fine sand, said in the journal of the borehole to come from a hard sandstone from which water at 113° Fahr. issued at the rate of 42,700 gallons a day.
3452 ,, Brown sandy grit; said to be very hard to bore through.
3460 ,, Fine-grained quartz sand with small bits of slaty and gritty rock; much yellowish-brown clay with the sand. Water at 124° Fahr. issued at the rate of 124,000 gallons a day, according to the journal.
3466 ,, Brown sandy grit.
3469 ,, Brown gritty sandstone with fragments of hard slate, and brown and yellow sand.
3530 ,, Greyish-brown sand, small slate pebbles and a piece of black lignite.
3565 ,, Brownish sandy material with slate fragments, said to be very hard to bore through.

From about this depth a large lump of apparently Bokkeveld slate was shot out of the hole while the rods were being raised.

The boring was discontinued at 3630 feet.

Dr. Kitchin writes of the pieces sent to him: "I take all these clays to be from an estuarine and fresh-water series of Wealden facies; and although there is no decisive palaeontological evidence for Wealden age, I should think that they

may quite well be in part contemporaneous with the marine development of the Uitenhage series, and perhaps in part of earlier Neocomian age. Accurate correlation with the marine facies, on palæontological grounds, is of course excluded.

Many of the crushed lamellibranches are probably referable to *Cyrena*, but the correctness of this reference could only be proved by ascertaining the nature of the hinge, and unfortunately no hinges can be seen in the specimens sent. But the shape, so far as can be made out, and the concentric linear markings of the external surface, are compatible with this determination.

The character of this bluish-green clay and the mode of preservation of the fossils are strongly reminiscent of some of the Wealden clays of England."

The site of the bore-hole lies about two miles south-south-east from the disused clay pit near the main line of railway beyond Rawson bridge,[1] where the dip of the clays and sandy clays is 2°–3° towards east 35° north. The character of much of the clayey rock from the bore-hole is the same as that of the clay-pit beds, but the genera of mollusca found in the latter[2] (*Actaeonina* and *Bochianites ?*) have not been identified from the bore-hole. The statement[3] that some of the fossils from the bore-hole are like those from the clay-pit has not been supported by the determinations made by Dr. Kitchin, for the bore-hole shells are not marine forms.

The dip of the beds in the bore-hole is, of course, unknown, but there is no reason to suppose that it is higher than that of the beds at the clay-pit. Until the country round Bethelsdorp has been fully examined, a discussion of the stratigraphical relationship of the beds pierced by the bore-hole must be incomplete. From G. W. Stow's account,[4] written in 1870, it is certain that the Bethelsdorp beds are marine, and presumably, at least, the bulk of the beds at the bore-hole lie below these.

It is noteworthy that, although a few pebbly beds were penetrated at shallow depths and again below 3000 feet, there is no evidence of the existence of thick conglomerates with quartzite boulders, such as are found near Enon, in the upper part of Zwart Kop valley and other areas where the Uitenhage series occurs. It is, of course, possible that the increasing difficulty in boring at the end of the work was due to hard boulders, but perhaps the base of the series here resembles

[1] Ann. Rep. Geol. Com. for 1900, p. 7.
[2] Annals of the South African Museum, vol. vii., p. 220.
[3] Introduction to the Geology of Cape Colony, 2nd edition, 1909, p. 301.
[4] Quart. Journ. Geol. Soc., vol. xxvii., pp. 506-7.

that exposed on the road to Humansdorp from Uitenhage where it leaves the Zwart Kop valley. The thick conglomerates with quartzite boulders are not seen there, but the Bokkeveld beds are overlain by sandy conglomerate with boulders and pebbles of Bokkeveld slate.

An analysis of the water issuing from the bore-hole at a temperature of 125° Fahr. was made by Mr. J. G. Rose, Government Analyst, with the following results:—

| | Grains per gallon |
|---|---|
| Calcium carbonate .. .. | 1·57 |
| Magnesium carbonate .. .. | 2·21 |
| Magnesium sulphate .. .. | 2·12 |
| Sodium sulphate .. .. .. | ·61 |
| Sodium chloride .. .. .. | 25·57 |
| Ferrous carbonate .. .. .. | 1·86 |

The composition of this water reminds one of the mineral water spring at Balmoral, in the Uitenhage district, where warm water, of which no analysis seems to have been published, deposits various substances containing iron.[1]

[1] Ann Rep. Geol. Com. for 1905, pp. 42-3.

# INDEX.

N.



O.



P.



Q.

R.



S.



T.



U.



V.

# CAPE OF GOOD HOPE.

DEPARTMENT OF MINES.

# FIFTEENTH ANNUAL REPORT OF THE GEOLOGICAL COMMISSION.

1910.

(*To be Presented to Parliament.*)

CAPE TOWN:
CAPE TIMES LIMITED, GOVERNMENT PRINTERS.
1911.

[U.G. 31.—1911.]

B.480.1700.7.11.
C.T.Ltd.—B641.

# FIFTEENTH

# Annual Report of the Geological Commission,

## 1910.

---

CONTENTS.

## GEOLOGICAL COMMISSION OF THE PROVINCE OF THE CAPE OF GOOD HOPE, 1910.

### MEMBERS OF THE COMMISSION.

THE RIGHT HON. JOHN XAVIER MERRIMAN, M.L.A.

THOMAS MUIR, C.M.G., LL.D., F.R.S.
Superintendent-General of Education.

THOMAS STEWART, M.I.C.E., F.G.S.

ATHELSTAN HALL CORNISH-BOWDEN, Surveyor-General.

FRANCIS EDGAR KANTHACK, A.M.I.C.E., Director of Irrigation.

*Secretary*—
THEODORE MACKENZIE.

### SCIENTIFIC STAFF.

*Director*—

ARTHUR WILLIAM ROGERS, Sc.D., F.G.S.

*Geologist*—

ALEX. LOGIE DU TOIT, B.A., F.G.S.

Geological Commission,
South African Museum,
Cape Town, 4th May, 1911.

SIR,—

I have the honour to forward herewith the Report of the Geological Commission of the Cape Province for the year 1910.

From that document it will be seen that good steady progress has been made and that facts of scientific and possibly economic importance have been brought to light.

The divergence of the system under which the Geological Surveys of the different parts of the Union are carried on is a matter that is, I am aware, engaging your attention and you are in possession of the views and wishes of the Geological Commission on this subject.

I take this opportunity of expressing the hope that whatever be the decision as to the future control of operations, steps will be taken to give that recognition of the services of Dr. Rogers and Mr. du Toit, which their scientific attainments as well as their long and meritorious service deserve.

I have the honour to be,

Sir,

Your obedient Servant,

JOHN X. MERRIMAN,
Chairman, Geological Commission.

The Secretary
of the Interior.

# GEOLOGICAL COMMISSION.

## DIRECTOR'S REPORT FOR 1910.

During the past year field work has been carried on in the Divisions of Beaufort West, Fraserburg, Sutherland, Laingsburg, Victoria West, Barkly East, Maclear, Elliott, Mount Fletcher, Mount Ayliff, Engcobo and Qumbu.

In November, 1909, on the request of the General Manager of Railways, a survey of the country surrounding the recently-opened coal in the Laingsburg and Sutherland Divisions was begun. The immediate object of the work was to discover the nature of the bodies of coal and to furnish advice as to the prospects and future development of the coal-bearing area. The occurrences at Wilgebosch Kloof and Hartebeest Fontein proved to be fresh examples of the type of coal-filled fissures long known to exist in the Beaufort West and Aberdeen Divisions, on which much time and money have been spent in vain since the late seventies of last century. A description of the coal is given in the following pages. It is certain that the discoveries yet made have at the present time no economic value ; and from the apparent absence of coal-seams from the Great Karroo, a country singularly favourable to the discovery of seams if they exist, the chances of the fissure coal being in any way connected with seams of coal are very remote. The fissures filled with coal offer a very interesting problem, but it is more than doubtful whether further investigations will prove of commercial use, at any rate in the near future.

I spent seven and a half months between Beaufort West, Loxton and Sutherland, mapping a large area of Beaufort beds and the dolerite intrusive in them. A large part of the country surveyed falls within Sheet 13 of the coloured map, which was commenced by Prof. Schwarz in 1896. This Sheet has been issued since the end of the year.

Mr. du Toit spent six months in the Transkei, continuing the work done by him in 1903-4 in Elliott and Barkly East. The work brought out the fact that the Stormberg beds were tilted and disturbed to a considerable degree in the south-west of Maclear immediately before and during the volcanic

out-bursts of that region. The intimate connection between the Cave Sandstone and the volcanic rocks is again illustrated by the results of the survey, for the Cave Sandstone is partially replaced by volcanic ash which attains a thickness of over 1,500 feet. Special attention was paid to the Gubenxa coal-field, a map of which is printed with the report, and to the coal seams in the Molteno beds elsewhere in the district surveyed.

The most interesting feature in this Annual Report is the account of Mr. du Toit's examination of the Insizwa intrusive rocks and the alteration of the sedimentary rocks (Beaufort beds) at their contacts. Though the igneous rocks are part of the great dolerite intrusions of the Karroo region, they are unlike any portions that have been previously described ; they are more basic than the usual dolerite and they range from gabbro and norite to picrite in composition. The surrounding Beaufort beds have been converted into biotite and cordierite-hornfels. The igneous rocks of Insizwa may prove to have considerable economic importance, for they contain sulphides of copper and nickel, which have been concentrated along the contact with the Beaufort beds. Though the ores were original constituents of the igneous rock they also occur in the altered Beaufort beds in the immediate neighbourhood of the contact. The ores have been found to contain platinum. The value of these deposits has still to be proved, and a prospecting syndicate is at work on them at present.

Though maps of the whole area examined by Mr. du Toit had not been made, the Secondary Triangulation had been carried through it, and the positions of points which had not been published were kindly given by the Director of the Secondary Triangulation.

The thanks of the Commission are due to Dr. Broom for determinations and short descriptions of fossils on which he is working, and to the Rev. J. H. Whaits, of Beaufort West, who has given most valuable information as to the localities of fossils found by him in the Beaufort West and Fraserburg Divisions. These facts have been used in the Report and in the preparation of Sheet No. 13 of the coloured map.

During the year Sheets 32 and 40 of the coloured map were issued.

The following papers written by myself were printed during the year :—

" The Iron Ores of Cape Colony," in " The Iron Ore Resources of the World." International Geological Congress, 1910, Stockholm.

"Past Climates of Cape Colony" in "Postglaziale Klimaveränderungen." International Geological Congress, 1910, Stockholm. "The Kheis Series." Geological Society S.A. Vol. XIII.

In the last Annual Report it is stated (p. 116) that "no analysis seems to have been made" of the water from the warm spring of Balmoral, Uitenhage Division. At the time that was written I had not seen the Report of the Senior Analyst for the year 1908; in it (pp. 121 and 122) there is a reference to that spring, and an analysis is given which shows that ferrous carbonate is not present, as had been supposed (Annual Report Geological Commission for 1905, p. 42), but that "possibly ferrous sulphate may be present in the water as it issues from the spring's mouth."

ARTHUR W. ROGERS.

# GEOLOGICAL COMMISSION.

## General Abstract of Receipts and Disbursements for the Year ended 30th June, 1910.

| | £ | s. | d. | £ | s. | d. |
|---|---|---|---|---|---|---|
| To Balance as per Cash Book, 1st July, 1909 ... ... ... ... | | | | 49 | 14 | 6 |
| „ Government Grant ... ... ... | 1,500 | 0 | 0 | | | |
| „ Sale of Wagon and Donkeys... ... | 104 | 7 | 6 | | | |
| „ do. Maps and Reports ... ... | 3 | 18 | 0 | | | |
| „ Fees... ... ... ... ... ... | 140 | 5 | 4 | | | |
| | | | | 1,748 | 10 | 10 |
| „ Advances (Current), repaid by vouchers | | | | 125 | 0 | 0 |
| | | | | £1,923 | 5 | 4 |

| | £ | s. | d. | £ | s. | d. |
|---|---|---|---|---|---|---|
| By Salaries ... ... ... ... | 966 | 13 | 4 | | | |
| „ Allowances (Personal) ... ... | 228 | 15 | 0 | | | |
| „ do. (Horse)... ... ... | 29 | 0 | 0 | | | |
| „ Transport ... ... ... ... | 43 | 14 | 8 | | | |
| „ Postages ... ... ... ... | 5 | 16 | 11 | | | |
| „ Printing, Books and Magazines ... | 27 | 14 | 10 | | | |
| „ Rock Sections ... ... ... | 13 | 9 | 8 | | | |
| „ Boys' Wages ... ... ... | 41 | 16 | 0 | | | |
| „ do. Food ... ... ... | 15 | 4 | 9 | | | |
| „ Purchase of Donkeys and Oxen ... | 67 | 0 | 0 | | | |
| „ do. Wagon... ... ... | 70 | 13 | 6 | | | |
| „ Equipment and Maintenance ... | 14 | 15 | 6 | | | |
| „ Grazing ... ... ... ... | 3 | 11 | 0 | | | |
| „ Food for Donkeys and Oxen ... ... | 1 | 6 | 8 | | | |
| „ Extra copies of Annual Report ... | 16 | 4 | 6 | | | |
| „ Horse Purchase Loss ... ... | 26 | 0 | 0 | | | |
| „ Miscellaneous ... ... ... | 0 | 7 | 0 | | | |
| | | | | 1,572 | 3 | 4 |
| „ Advances made ... ... ... | | | | 125 | 0 | 0 |
| „ Balance ... ... ... ... | | | | 226 | 2 | 0 |
| | | | | £1,923 | 5 | 4 |

(Signed) THEODORE MACKENZIE, Secretary.

Audited and found correct,
(Signed) WALTER E. GURNEY,
Controller and Auditor-General.

Audit Office, Pretoria, 8th August, 1910.
J. S. B.

# GEOLOGICAL SURVEY

OF

# PARTS OF THE DIVISIONS OF BEAUFORT WEST, FRASERBURG, VICTORIA WEST, SUTHERLAND AND LAINGSBURG,

BY

A. W. ROGERS.

# GEOLOGICAL SURVEY

OF

# PARTS OF THE DIVISIONS OF BEAUFORT WEST, FRASERBURG, VICTORIA WEST, SUTHERLAND AND LAINGSBURG.

The country described in the following pages includes the north-western part of Beaufort West, the southern part of Fraserburg with an adjoining strip of Sutherland, and the extreme north-eastern corner of Laingsburg, and the southern row of farms in Victoria West from Abram's Kraal to Laken Vley. A narrow belt between the town of Carnarvon and the Zak River drift at Manhaar's Kraal was also examined.

This area is continuous with the country on the south side of the Nieuweveld, mapped by Prof. E. H. L. Schwarz in 1896,[1] with the area mapped by that geologist and the writer in 1902,[2] and with the country surveyed by Mr. A. L. du Toit and the writer in 1903.[3]

A large part of the area is represented on sheet 13 of the geological map of the Cape Province.

Beyond the alluvial deposits in the valleys, all the sedimentary rocks in the district belong to the Beaufort series, and they lie throughout at a low angle, often horizontally. They are traversed by dykes and sheets of dolerite, and by a few dykes of lamprophyre and pipes filled with rocks allied to kimberlite.

The chief fact concerning the physical features of the district is the presence of part of the main watershed of the Cape, which runs for about 170 miles through the area in a general east-north-easterly direction. To the north of the sinuous course taken by the watershed, the surface water drains away to the north-west to form the Zak River, which joins the Olifant's Vlei River in Kenhardt.

The gradients of the head-streams of the Zak are low, and in this respect these streams are in strong contrast to those draining the southern slope of the watershed west of the town of Beaufort West. The average level of the watershed in this region (*i.e.*, between Kuil's Poort on the east and the Komsberg on the west) is probably about 5,000 feet, though in places it exceeds 6,000 feet, as at Bulthouder's Bank, 6,271 ;

---

[1] 1st Annual Report of the Geological Commission, for 1896, p. 15.
[2] 7th Annual Report of the Geological Commission for 1902, p. 99.
[3] 8th Annual Report of the Geological Commission for 1903, p. 9.

Steenkamp's Poort, 6,276[1]; to the south the level of the stream beds drop to 3,000 feet within a very few miles, often within one mile, while to the north-west that level is only reached at a distance of 40 miles or more from the watershed. The water from Kuil's Poort and the country to the west goes into the Gamka and Dwyka Rivers, which enter the Indian Ocean as the Gouritz River. North and east of Kuil's Poort the drainage lines go to form the Salt River, which joins with others to the east to form the Gamtoos, which enters the ocean between Humansdorp and Port Elizabeth. The head streams of the Salt River have much less steep gradients than those of the Gamka and Dwyka. The level of the watershed in their region is on the average lower by 800 feet or so than to the west of Kuil's Poort, though blocks of high ground reaching the 6,000 feet contour are left standing within the southern drainage area. The river crossed by the railway line near Nel's Poort reaches the 3,000 feet contour near that station, at a distance of over 40 miles from its source on Gert Adrian's Kraal.

Nieuweveld is the name by which the high country west of Kuil's Poort is known, and on the south it is limited by the well-marked escarpment overlooking the Gouph or Great Karroo; to the north there is a gradual descent towards the valley of the Orange River. North and east of Kuil's Poort there is no such distinct escarpment, because the tributaries of the Salt River have cut so deeply into the high ground. The reason of this difference in the shape of the country is not easy to find, but it cannot be due entirely to the behaviour of the great dolerite intrusions, which are just as important to the east of Kuil's Poort as to the west.

The change in the character of the country south of the watershed, from a very hilly region to one in which flat areas predominate, coincides fairly closely with the southern limit of the dolerite intrusions east of the Komsberg. Where the intrusions cease, the surface becomes flatter. In the Komsberg region the dolerite intrusions disappear from the surface several miles to the north of the escarpment, and thus lie wholly within the northern drainage area; near the town of Sutherland the dolerites are first met with from twelve to fifteen miles behind the escarpment. Below the Komsberg, therefore, there is no distinction between a hilly country within the dolerite region and a flatter one to the south of it; the country there, drained by the Buffel's and Dwyka Rivers, is more hilly throughout, although made of the Beaufort and Ecca beds, which extend eastwards through the Gouph.

[1] These figures are taken from the Report on the Geodetic Survey of South Africa, vol. ii., p. 231, 1901: by Sir David Gill.

The only river in the district which has running water in it for some months at a time is the Zak, but this is only the case for some 20 miles of its course below the sources on Pieter's Vley[1] and Paarde Kraal; elsewhere open water is confined to occasional pools, the zeekoegats or kolks, for at least the greater part of the year.

The country drained by the Zak and its tributaries in the district under consideration is characterised by plains near the larger streams and plateaux rising from them in successive terraces by sharp ascents over outcrops of strong sandstone bands. While there is usually a fair covering of soil on the larger river plains, the plateaux are but thinly covered with soil and have angular and subangular fragments of rock scattered over them rather thickly. The sandstones which determine the positions of the plateaux crop out occassionally on them, and the mudstones which lie between them are not often seen except in the escarpments just below the sandstones. The dolerite intrusions are the chief disturbing element in the otherwise monotonous landscape. They give rise to ridges, or pronounced plateaux and outliers, according to their form, as will be explained in the section of this Report dealing with the dolerites. They are also the indirect cause of the production of wide plains in the river valleys. The Zak River affords many instances of such plains. At a distance of only a mile from the edge of the escarpment east and west of Bulthouder's Bank there is the first patch of vley-ground in the course of the Zak River. The edge of the escarpment at the head of the tributary on either side of the Bank, a thick outlier of dolerite, is made of shale or rather thinly-bedded hardened mudstone with thin beds of sandstone intercalated; a small flat area, in which sandstone and mudstone crop out, has been cut by the two tributaries of the Zak, where they join to traverse the thick dolerite of Bok Kraal. This dolerite is a sheet which ends abruptly on the north along a nearly straight east and west line, which is seen on Paarde Kraal to the east to be the north surface of a dyke. The Zak River has cut a gorge three miles long in this sheet, and at places over 300 feet of dolerite are seen in the walls of the gorge, though the base of the sheet is not exposed in it, except in the vley at its south end. There can be no doubt that the existence of this vley is due to the fact that the erosion of the river bed was checked by the hard dolerite, and so the river was able to widen its valley comparatively

[1] This name is written Putter's Vley on the Divisional map and on the 1 : 800,000 map of Cape Colony, published by the Surveyor-General in 1895, but according to the owner and other residents in the neighbourhood it should be Pieter's or Petrus Vley.

rapidly above this bar. On emerging from the gorge, along which it is extremely difficult to make one's way with a horse, the river traverses a wide shale and sandstone plain on Groote Vley, where it is flanked by a large tract of vley ground. This very flat ground is succeeded by a narrow valley and then a short gorge on Wittehart, where it traverses a second rather thick sheet of dolerite. On Wittehart and Waterfall there is some comparatively open ground along the river before it enters a narrow gorge due to a third great sheet of dolerite[1] along its course, but as hard and thick sandstones are present here, the effects of lateral erosion are much less marked than where mudstones predominate. On Quagga's Fontein (Dunedin) there is a plain about five miles long and in places three miles wide transversely to the river's course, behind the remarkable ring-shaped dolerite intrusion of Kaffir's Kraal, which is entered and left by narrow poorts. The ground within the ring of dolerite is made of sandstone and mudstones, and although it is fairly level compared with that made of the surrounding dolerite, there are no wide, flat tracts in it. On leaving the lower poort of Kaffir's Kraal, the river runs over flat ground for six miles, with occasional wide pans lying at a level of eight or ten feet above its bed, before it meets with the sheet on Drie Fontein. Just at the southern corner of Drie Fontein and Lap Fontein the river crosses a rather thin, highly inclined sheet or dyke, but although this is the same curved dyke which forms such a conspicuous ridge both to the north-east and north-west, where it is much thicker, it has had little effect on the river valley here. From the southern boundary of Drie Fontein to Koopman's Graf (now called Zak River Poort) the river lies within the area enclosed by the great curved dyke, and it cuts through at least six small intrusions as well as the thick sheet of Drie Fontein, and the ground is very uneven as a whole, but there is a well-marked flat just behind the thick portion of the curved dyke at the poort itself. Below this poort and above the Riet Poort sheet there is another flat underlain by mudstone and thin sandstone; after leaving this sheet, which it traverses by a narrow gorge, the river flows through a valley with very gentle slopes for some eight miles, till it meets the sheet on Kruis van Bloem Fontein, in which it has cut a steep sided valley. Beyond this sheet the Zak River crosses six small intrusions in the remaining thirteen miles of its course in the district surveyed, but it presents no further contrasts of note.

The occurrence of open plains of various sizes behind masses of dolerite, illustrated by the foregoing account of the main

[1] These three inclined sheets are really parts of one great mass of dolerite.

stream of the northern drainage slope is repeated in practically all the other valleys in the district. In the case of the smaller streams the poorts are often partly closed by dams ; probably more than half of the dams are in such places.

It is evident that the profile of the rivers is step-like, being divided up into long portions with very low grade and shorter ones with high grade, but there are no vertical falls except in the smaller tributaries, and in these the falls seem to be confined to the upper parts of the course.

Though the number of well-defined pans in this area is very small, the bare, mud-covered surfaces, on which water stands to a depth of an inch or so after rain, are abundant. These surfaces are ill-defined and often large, measuring from 500 yards or less to over two miles in width ; they are called pans by the residents in the district. In appearance, they are like the pans in parts of Kenhardt and Carnarvon, occupied by the Karroo formation and described in last year's Annual Report.[1] The covering of mud is thin, and the surface smooth, often so smooth that it reflects light almost as well as wet mud. They are found in many parts of the Nieuweveld, and are perhaps specially abundant within five miles of the main watershed. I was told that the series of droughts the country has suffered during the last 12 years has greatly enlarged these pan-flats on Reger's Vley and the neighbouring farms, because the small bushes which died early in the droughts have never been adequately replaced by new growth. My informant said that the size of the pans fluctuates and is at present diminishing, and that three or four seasons with moderately good rains would cover them entirely with bush.

These ill-defined pans do not occur on dolerite, but the only clearly-marked pans seen in the district were entirely surrounded by dolerite. I only saw four of these pans, but I was told of four others in similar situations.

Two of the pans visited were on the top of Paarde Berg, a dolerite-capped mountain, rising 1,500 feet from the surrounding country on the northern border of the Beaufort West Division. The top of Paarde Berg, which is between seven and eight miles long in a north-westerly direction, is fairly flat ; from below and from a distance it looks as though it were quite flat. In the south-west corner there is a depression 50 feet deep and 250 yards long by about 100 yards wide, with the longer axis lying E.10° N. The floor is covered with loose boulders of dolerite resembling in texture and general appearance that of the sheet in which it lies; the blocks are

[1] Annual Report Geological Commission for 1909, pp. 12-14.

roughly rounded, just as are those found scattered over the rest of Paarde Berg and other high-lying surfaces of coarse dolerite in the district; they vary in size from three feet in diameter downwards. The sandy mud seen between and below the boulders is grey in colour and contains fragments of felspar and augite, recognisable under a pocket-lens; it resembles the usual red sandy soil found on all such dolerite mountains in everything except colour, for those soils are always red. No material foreign to dolerite was found either in the sandy mud or the boulders lying on it. There were no outcrops seen on the floor. The slopes bounding the depression are rather steep and are covered with large blocks and outcrops of dolerite, as well as with smaller boulders. There is no outlet, and the pan does not lie in the course of a slightly-marked valley. It is separated from the precipitous face of the mountain by about 100 yards of dolerite-strewn ground with occasional large outcrops. A second pan occurs a few hundred yards to the east, but it is smaller than the first, and if the water were more than two feet deep it would flow to the east down a steep kloof, which has been cut deeply into the south-eastern part of the mountain. The second plan has fewer boulders strewn over its surface than the first. I was told by Mr. de Bruyn, of Abram's Kraal, that there are two similar pans on the north-west and north-east corners of Paarde Berg, but I did not see them. Mr. de Bruyn said that these pans hold water after rain, and that in former years the pan in the north-west corner usually held enough water throughout the year for the large stock kept up there. At the time of my visit all the pans were dry.

On the large dolerite-capped mountain, which stretches from behind Steenkamp's Poort house, south-westwards to the south-eastern beacon common to Steenkamp's Vlakte and Thee Kloof there are three pans lying on a line running N. 8°E. One of them is 1,200 feet above the Thee Kloof road at the summit of the Pass, the other two are at a slightly lower elevation. They are in general like those described on Paarde Berg, but on the whole more free from dolerite boulders. The southernmost pan is rather irregular in shape, 170 yards long by 80 wide, and is bounded by rough dolerite slopes, rising from 30 to 50 feet above the floor. The greater part of the floor is made of grey sandy mud, in which the débris of dolerite is easily recognised. There is a bank of grey sand at the south-western side, evidently blown by the wind from the pan floor. The most interesting feature in this pan is the presence of three large flat outcrops of dolerite on the floor, irregular in shape, but reaching 40 yards in length by

20 in width. The only rocks beyond dolerite seen in or about the pan were fragments of hardened mudstone, lydianite or very fine-grained hornstone, such as is found at dolerite contacts; these fragments were evidently carried to the pan by natives for the purpose of making stone implements. The second pan to the north is rather longer than the first and had no outcrops on the floor. The third was not visited; it lies about a mile further north.

I was told that a similar pan exists on the dolerite-capped mountain south of Drooge Kloof.

These four pans near Thee Kloof are said to retain water for a short time only after rain, for a shorter time than the large but very shallow pans on the mudstone and sandstone of Steenkamp's Vlakte.

The origin of these pans on high surfaces of dolerite is not easy to understand. They differ markedly from the large pans in this and other districts in their definite limits, steep sides and smaller size. When first seen they give the impression of being due to the existence of similarly shaped outcrops of softer rock, such as tuff, lamprophyre or kimberlite, and a careful search was made for fragments of foreign rocks which would be expected in such cases. No sign of this were found; and although pits would have to be sunk in the floors to decide the nature of the underlying rock, it seems probable that the pans are really depressions in the dolerite itself. The large dolerite surfaces on the floor of the southernmost pan above Steenkamps Vlakte go far towards corroborating this opinion, for it is most improbable that three such large surfaces should be found on about the same plane were the blocks merely inclusions in a softer matrix, which had given rise to the depressions by its easy removal. Considering, however, that there are pipes and fissures in the district it is possible that the pans are due to their existence.

In the absence of soft rock which would allow of the easy removal of its debris by wind it is certainly difficult to understand why such deep depressions should be formed. Were they formerly filled with mudstone or sandstone they should retain portions of those rocks. Large but thin remnants of overlying sediments are not uncommon on the high level streets of Beaufort West and Fraserburg, and their preservation is in part due to the hardening effect of the dolerite; if they were further protected by being enclosed by dolerite at the sides, their resistance to the weather would be greatly increased.

There seems no escape from the conclusion that the depressions are due primarily to rapid local disintegration of

the dolerite, but why this took place is unknown. The wind may very probably have removed the disintegrated material ; no considerable aid from animals could be expected, in the case of pans situated as these are, though in different surroundings there can be less doubt of the efficiency of their action.[1]

## The Beaufort Series.

Rocks belonging to the Beaufort series immediately underlie the surface over the whole of the area under consideration, excepting those parts occupied by the intrusive dolerite.

For the most part the beds lie flat, or very nearly so ; in the south-western corner of the district, in Sutherland and the extreme northern corner of Laingsburg, there is a general low dip to the north-north-east or north-east, which is probably persistent enough to carry the beds downwards in that direction in spite of the occasional contrary dips that are seen.

Though the dips are too low to be easily seen, there is a general north-easterly or northerly dip throughout the area about the head of the Gouph, and it is owing to this dip that the escarpment is cut in higher and higher beds as it is followed from the Komsberg to the north of Beaufort.

The lowest beds in the southern part of the area are those seen near the head of the Dwyka valley, where the river leaves the Roggeveld at Wilgebosch Kloof. The highest are those between Bulthouder's Bank and the country north of Gert Adrian's Kop. It is impossible at present to state the exact thickness of the Beaufort series seen in this area, but it is probably over 6,000 feet.

Owing to the recurrence of rocks with very similar characters throughout the succession, the changes that can be observed to take place along any one horizon when followed over several miles of country, and to the frequent interruption of the sedimentary outcrops by intrusions of dolerite, the mapping out of the Beaufort beds in this area would take a long time ; and at present it is impossible to say what beds on the escarpment behind Beaufort West represent those exposed at any particular point on the Orange River drainage slope, for instance, at the drift through the Zak River at Stof Kraal in Fraserburg.

The fossils are, at present, of little use, for they are so scarce that the time required to make adequate search throughout the district is too great to allow such a search to be undertaken in the course of the present survey ; and, as a rule,

1. The best discussion of this subject will be found in Dr. S. Passarge's "Die Kalahari," ch. xvii.

the only specimens which give definite information are skulls ; too little is known of other parts of the Karroo reptiles to enable specific or even generic names to be assigned to isolated bones, except in a few cases.

In time a large amount of information as to the localities of determined species and genera of reptiles will be collected, but at present the facts are far too scanty to afford a basis for any but a vague and ill-defined subdivision of the Beaufort series.

In a paper published in 1905, Dr. R. Broom[1] subdivided the Beaufort series according to the distribution of the vertibrate remains. The parts of his classification which affect the area dealt with in this report are :—

*Middle Beaufort series.*

Lystrosaurus beds :—*Lystrosaurus, Atherstonia.*

*Lower Beaufort series.*

Kistecephalus beds :—*Cynodraco, ? Cynochampsa, ? Cynosuchus, ? Scaloposaurus, Theriognathus, Dicynodon, Oudenodon, Kistecephalus.*

Endothiodon beds :—*Cynodraco, Aelurosaurus, Ictidosaurus, Ictidosuchus, Scylacosaurus, Scymnosaurus, ? Gorgonops, Lycosuchus, Dicynodon, Oudenodon, Endothiodon, Esoterodon, Cryptocynodon, Pristerodon, Opisthoctenodon, Prodicynodon.*

Pareiasaurus beds :—*Lycosuchus, Glanosuchus, Titanosuchus, Scapanodon, Delphinognathus, Tapinocephalus, Pareiasaurus, Pelosuchus, Dicynodon, Oudenodon.*

In a more detailed list published in 1909,[2] Dr. Broom adds the genera *Saurosternon* and *Propappus* to the Endothiodon fauna, and the genera *Elonichthys, Rhinesuchus, Alopecodon, Pardosuchus, Arnognathus, Trochosaurus, Hyaenasuchus, Eunotosaurus, Pelosuchus,* and *Scymnosaurus* to the Pareiasaurus fauna. *Scymnosaurus* is removed from the Endothiodon beds down into the Pareiasaurus beds.

Dr. Broom has kindly given me a list of the reptiles known to him from the neighbourhood of the town of Beaufort West and Kuils Poort. In the plain round the town are *Endothiodon uniseries* Ow., *Diaelurodon whaitsi*, Br., *Aelurosaurus felinus* Ow., *Aelurosaurus whaitsi* Br., *Scymnosaurus* sp., and small species of *Dicynodon* and *Oudenodon*.

---

[1] R. Broom. On the classification of the Karroo system of South Africa. Papers read at the joint meeting of the British and South African Associations for the Advancement of Science, 1905, vol. ii., p.p. 38-46.

[2] Annual South African Museum, vol. vii., pp. 285-291.

In the rocks up to 1,000 feet or so above the town on the escarpment near Kuils Poort are *Taognathus megalodon* Br., *Aloposaurus gracilis* Br., and species of *Oudenodon* and *Dicynodon*.

In the highest beds at Kuils Poort are *Ictidognathus parvidens* Br., *Aelurosaurus tenuirotris* Br., *Oudenodon bolorhinus* Br., *Dicynodon* sp., *Kistecephalus microrhinus* Ow. These beds lie at least 1,500 feet above Beaufort West, probably 1,700 or 1,800.

In the 1905 paper Dr. Broom says (p. 40) that the Lystrosaurus beds stretch as far west as Fraserburg, but this is probably not the case, for the beds round Fraserburg village containing *Propappus*[1] belong to a lower horizon than those at the edge of the Nieuweveld south of the village, and they are probably not far from the horizon on which *Propappus* was found at Hoedemaker, on the escarpment itself. A crushed skull which Dr. Broom refers to *Alopecodon* was found on Schaaps Koi, south-west of Fraserburg village, very slightly if at all lower in stratigraphical position than the beds near the village containing *Propappus*. The latter, or a very similar form, occurs also on Regers Vley, at the top of the escarpment north of Brandewyn's Gat.

The Pareiasaurus beds probably form the upper part of the Moordenaars Karroo[2] and a large area on the top of Komsberg, for large bones in a fragmentary condition, together with pieces of jaw with teeth just like those of *Pareiasaurus*, but without any button-shaped dermal scutes that are so abundant in *Propappus*, were found on the northern part of Rogge Kloof. The thickness of the Pareiasaurus beds is probably very considerable, over 2,000 feet perhaps. From the Komsberg the top of the beds gradually drops to the level of the Gouph, and they cover a greater and greater area of the country south of the great escarpment the further east one goes. Near Beaufort West, according to Dr. Broom's determination of fossil bones, the Endothiodon beds form the flat country and 1,000 or 1,200 feet of the escarpment; the *Kistecephalus* beds form the higher part of the escarpment overlooking the railway on the west, between Beaufort and Rhenoster Fontein; and the *Lystrosaurus* beds occur in the country behind this front escarpment, *i.e.*, round Gert Adrian's Kop.

The largest collection of *Propappus* bones was obtained on the escarpment of Hoedemaker's Kraal 800 feet above the river and about 4,500 feet above the sea. Unfortunately the

[1] This statement is based on information given me by Rev. J. H. Whaits.

[2] See Annual Report Geological Commission for 1902, pp. 118-119.

head could not be found; it had probably dropped out from the cliff and become buried under rubble lower down. The skeleton is being described by Dr. Broom. In the same locality and the same beds, grey and purplish mudstones, were found several small *Dicynodon* skulls, and on a slightly higher horizon in Thee Kloof a large *Dicynodon* skull was obtained by Mr. Le Roux of Thee Kloof and given to the South African Museum.

Just to the west of Fraserburg, on the farm Drooge Voets, Mr. Whaits obtained a fish, which Dr. Broom says is almost certainly an *Elonichthys*, and a small amphibian, which Dr. Broom says is "a small temnospondylous stegocephalian, whose total length when complete was probably about two feet. The head is moderately flat and nearly as broad as long. It measures 2½ inches in length, and the orbits are in the anterior half. The ribs are short, the body narrower than the head, and the limbs feeble. Is seems more allied to *Bothriceps* and *Micropholis* of the Upper Karroo than to any of the known European or American Permian types." He proposes the name *Phrynosuchus* for the genus to which this specimen belongs.

It is probable that the Endothiodon beds of Dr. Broom's classification occupy a wide area on the Nieuweveld between the Fraserburg-Sutherland boundary in the south-west and the railway line north of Beaufort; the only part which is probably made of higher zones is the block of mountainous country between Bastaard's Poort, Bulthouders Bank and the cliffs behind the Hope.

It is at present quite impossible to attempt to define the approximate position of the northern border of the Endothiodon beds. During the journey from Carnarvon to Fraserburg at the commencement of the work I searched every exposure near the road and made enquiries for bones. The only places where bones were seen north of the Zak River at the Stof Kraal drift were on the farms Gans Vley and Tabak Fontein. On the former fragments of bones and a small tooth were seen in a limestone band, and on the latter bones occur in a clay pellet conglomerate. I was told some large fragments occur on another part of Gans Vley.

To the south of the drift near Stof Kraal the first place where determinable bones have been found is the Fraserburg commonage.

The fossil bones occur in all varieties of sedimentary rocks found in the district. It is often held that they are practically confined to the shales, mudstones and clay-pellet conglomerates, and that they do not occur in the sandstones. So far

as the occurrences of bone *in situ* were concerned, they were seen as often in the sandstones as in the other rocks, except clay-pellet conglomerate. The fact that the actual area of flat ground and mountain slopes made of mudstone and shale exceeds that directly underlain by sandstones is partly responsible for the mistake referred to above. Bones are the most resistant part of the mudstones and shales, and they accumulate as they weather out; in the case of sandstones, the bones are destroyed by weathering before the matrix which encloses them, so that they are represented merely by hollows on the outcrops, with perhaps a few fragments of bone still adhering to the surface. Such hollows and fragments were frequently seen in Fraserburg Division and occasionally in Beaufort West, but I could not obtain from a sandstone any specimens worth carrying away.

Fossil plants are rare in these beds. Fragments of stems and leaves, which probably belong to *Schizonenra* or *Phyllotheca*, were occasionally seen, and also impressions, without the venation clearly preserved, of leaves of the *Glossopteris* type, but no good specimens were obtained. Mr. J. H. Whaits found the specimen, described by Prof. Seward under the name *Phyllotheca whaitsi*,[1] on Klip Fontein, in Fraserburg.

Klip Fontein is often referred to on account of the fossil discoveries made there by the late Mr. T. Bain and the visit paid to the place by the late Professor Seeley. Dr. Broom has kindly written the following note on the fossils. "About 1877 Mr. T. Bain discovered on Klip Fontein, near Fraserburg, a slab with fragmentary limb bones which was sent to the British Museum. This specimen was described by Seeley in 1888 under the name of *Theriodesmus phylarchus*, and was believed to be the remains of a primitive mammal. Some years later, he came to the conclusion that the remains were reptilian. In 1889 Seeley went to Klip Fontein with Mr. T. Bain, in the hope of getting other remains of *Theriodesmus*, but in this he was unsuccessful. He obtained, however, portions of two small skeletons and a very fragmentary skull. One skeleton, represented by a cast of a humerus, a few vertebrae, and a fragment of the shoulder-girdle, he made the type of a new genus and species, *Theromus leptonotus*. The fragmentary skull, he thought, might be referred to *Theromus*. The second fragmentary skeleton, represented by a left fore-limb, a number of dorsal vertebrae, and a few other fragments, Seeley made the type of a second new genus and species, *Herpetochirus brachycnemus*.

[1] Seward, Geological Magazine, 1907, p. 481. The locality is wrongly given as "Prince Albert in shale lying between the Witteberg series and the Dwyka conglomerate." The plant actually came from the Beaufort beds on Klip Fontein.

The types are so imperfect, and the illustrations given so poorly executed, that it is very difficult to make sure of these specimens, but in the light of some recent finds, there are one or two conclusions to which I think we may safely come.

The two small skeletons were got apparently close together. They both are skeletons of small Therocephalians, and they are approximately of equal size. The probability is, that they belong to the same species, and there seems to me nothing in the specimens that opposes this conclusion. The question next arises—is there any known Therocephalian skull that might be the skull of *Theromus?* Seeley believed the fragmentary skull he got might be; but in this he was, I think, certainly wrong. It is very much too large. In all known Therocephalians the skull is only about 1½ to twice the length of the humerus. If then the skull of *Theromus* was between two and three inches in length, the only skull hitherto discovered that might belong to it is the little one recently described by me as *Ictidognathus parvidens*, from Kuil's Poort and from the Kistecephalus zone.

The fragmentary skull obtained by Seeley, while it cannot possibly belong to *Theromus*, is just about the size we should expect the skull of *Theriodesmus phylarchus* to have been, and as apparently it was got in the same locality as the type, the probability is, that it may be the skull of *Theriodesmus*. The illustrations given of the skull are so extremely unsatisfactory that little can be made of them, but so far as one can judge it seems possible that the skull may belong to the species recently described by me as *Aelurosaurus tenuirostris* from the same horizon as *Ictidognathus*.

As, however, species founded on fragmentary limb bones can never be identified with certainty, both *Theromus leptonotus* and *Theriodesmus phylarchus* are regarded by me as indeterminate genera and species."

From the general structure of the Nieuweveld it is probable that Klip Fontein lies on beds of a lower horizon than those (Kisticephalus), beds at Kuil's Poort from which *Aelurosaurus tenuirostris* and *Ictidognathus* were obtained. The Klip Fontein beds are probably the same as those on the Hoedemaker cliffs which yield *Propappus*, and Dr. Broom thinks it likely that the fragment of *Pareiasaurus* reported by Seeley from Klip Fontein may belong to *Propappus*.

The general characters of the sedimentary rocks of the Nieuweveld escarpment and of the Gouph at its foot were described by Prof. Schwarz.[1] His description applies to the whole of the sediments seen between Beaufort West and Carnarvon, but the distinction between features produced by the thick yellow-brown weathering sandstones (defining

[1] Annual Report Geological Commission for 1896, pp. 15-17.

sandstones of the 1896 report) and the thinner but harder red-weathering sandstones (intermediate sandstones) becomes less and less as the country becomes flatter north of the Nieuweveld. In the flat country the hard red-weathering sandstones give rise to extensive plateaux or terraces, just as the thicker but looser textured sandstones do. On the escarpment, however, the larger terraces are always caused by the presence of the "defining sandstone," as Prof. Schwarz found near Beaufort West.

Under the microscope (2,531) the coarse "defining sandstone" is seen to be made chiefly of grains of quartz, orthoclase, and plagioclase, with a small amount of garnet and biotite. The grains are usually very closely packed, although they average about ·3 mm. in diameter; it is clear that alteration of their original form has taken place by the solution and redeposition of quartz, and that the original shapes have been obliterated. In places there is a very fine quartz mosaic in corners between the grains, but calcite plays a smilar rôle in parts of the slice. The orthoclase is much more altered than the plagioclase, and has small flakes of sericite in it. This specimen was taken from a core from a depth of 130 feet below the surface at Wilgebosch Kloof; the sandstone crops out on the hill sides but is rather crumbly and weathered at the surface.

A thin slice of the red-weathering sandstone (2652) from Fliege Kraal (Fraserburg), a fine grained bluish rock with a bright rusty red crust, is made of angular grains of quartz, orthoclase and plagioclase closely pressed together, so that it is difficult to determine what the cementing substance is. In parts of the slice calcite is the cement. There is some epidote which appears to have developed in the rock. Other minerals present as grains are garnet, apatite, tourmaline and greenish-yellow epidote. The grains rarely exceed .04 mms. in width. The slice was cut perpendicularly to the bedding, and there are distinct layers richer and poorer in quartz.

On De Kuilen there is a bed of sandstone of the coarser kind, which is more felspathic than usual and contains thin dark layers due to the presence of magnetite in numerous grains. A thin section of the brown-weathering rock of this bed (2530) shows a rather coarse even grained sandstone with more felspar than quartz in it. The quartz grains in places have fresh quartz grown on to them in crystalline continuity with that of the grains, but the outline of the grains is visible in such cases. The minerals present in small quantities are biotite and muscovite, garnet, zircon and sphene. The grains

are rather closely packed; there are a greenish chloritic material and quartz in the interstices.

The colour of the sandstones in this area is grey, bluish or greenish when fresh. Red sandstones were not seen at all, and purplish tints are very rarely seen in the sandstones, though fairly common in the shale and mudstones and very usual in the clay-pellet conglomerates.

False bedding is frequently seen in the sandstones, but it is rarely developed in a very marked degree. Ripple marks are frequent.

Clay-pellet conglomerates are found on very many horizons throughout the area. They always occur below a sandstone bed, but in many cases they merely occupy a shallow depression eroded in the underlying mudstone or shale, and are soon completely overlapped by the sandstone.

The thickest bed of clay-pellet conglomerate which was seen is exposed on the south side of the hill called Bushman's Berg, south-east of Bok Poort, on the farm Esterville, in Beaufort West. The hill is capped by some 30 feet of yellow-weathering sandstone, slightly false-bedded, which forms an overhanging cliff on three sides of the hill. This sandstone lies upon purplish shale as a rule, but on the south face a lenticle of clay-pellet conglomerate, which swells out to six feet in thickness, intervenes between the two. It is dull reddish in colour, with pellets of much finer-grained and more argillaceous red rock and also pellets of grey limestone. Small pieces of bone are occasionally seen. In thin section (2629) the matrix is made of fair-sized angular grains of felspar, quartz and a few flakes of mica cemented by carbonates; the included lumps are made of very small quartz and felspar grains in a semi-opaque and extremely fine-grained base without carbonates. The large grains of the matrix project into the fine-grained lumps, which appear to have been soft at the time of their inclusion. A section of a calcareous inclusion from this bed (2630) shows a granular crystalline calcite base, containing angular and subangular grains of quartz, felspars, and flakes of mica up to 2 mm. in diameter. The grains are nearer the size of those in the general matrix of the clay-pellet conglomerate than those in the clay-pellets. As in all the sandstones examined, the untwinned felspar grains are more weathered than the twinned. On the eastern side the bed of clay-pellet conglomerate described above contains many layers of sandstone like the overlying rock, and it is finely replaced entirely by those layers becoming more abundant.

The clayey beds in this district are mudstones and shales with more or less sand in them. The lamination is more or

less developed, and as it becomes indistinct the rocks can be called mudstones rather than shales. The colour of these rocks varies from grey through greenish tints to reddish purple. Pure red colours, such as considerable thicknesses of the Red Beds of the Stormberg series have, are not seen in the Beaufort beds. The prevailing colours of the Beaufort shales are greys and greenish.

Limestone in the form of nodules and thin lenticular layers, or large disc-shaped nodules, are of very frequent occurrence throughout the area in the shales and mudstones. A thin section (2626) of a disc-shaped lenticle of limestone on Klipplaat Drift (near Wagenaar's Hoek) shows a fine-grained rock with a granular calcite matrix containing scattered and very small angular grains of quartz, felspars and muscovite. The proportion of grains to matrix is much smaller than in the sandstones described above.

The limestone lenticles rarely exceed six inches in thickness.

Small lumps and branching tubular bodies of pinkish and white chalcedony are often seen in the limestones. All attempts to discover recognisable traces of organisms in these chalcedony masses failed. A thin section (2632) of a piece of such a chalcedony mass from Abram's Kraal (Victoria West) shows an oval area of quartz and calcite crystallized together and containing small flakes of a chloritic mineral; this area is surrounded by finely-crystalline chalcedonic silica, in which lies an irregular thin zone, concentric with the quartz-calcite area, rich in the chlorite and an epidote mineral.

Limestone is frequently found coating the fragments of bone in the shales and mudstones.

Local unconformities are very often seen in the Beaufort beds where clean sections are exposed on hill-sides or river banks. The thicker sandstones often cut out varying thicknesses of shale. In places it can be seen that at one end of a section, a hundred yards or more in length, there are quite 20 feet of shale or mudstone present, which are unconformably overlapped by an overlying sandstone bed.

Change in the nature of the sediment along particular horizons can frequently been seen to take place; prominent sandstone bands lose their character by the coming in of layers of shale and make a smaller and smaller feature as they are traced along a hill-side. A remarkably sudden change is well exposed in the left bank of the river on Schaaps Kooi. A band of blue and greenish shale, four feet thick, passes into yellow-weathering sandstone within a distance of one foot. The section as seen from a short distance gives the impression

of a faulted junction, but the rapid change is due to the deposition of sand instead of mud along a well-defined line. There is no unconformity between the two rocks, merely a change in the sediment deposited.

## The Nieuweveld Coal.

The first discovery of coal in the neighbourhood of the great escarpment appears to have been made in 1864 or 1865 on the farm now called Leeuw Rivers Poort, west of Beaufort West.[1] In 1875 coal was discovered on Buffel's Kloof in the Camdeboo, Aberdeen, about 80 miles east of Beaufort West.[2] The work done on those outcrops has proved that the coal occupies fissures, and that it is an anthracite. Though much trouble has been taken from time to time to find an ordinary seam, interbedded with the surrounding or underlying sedimentary rocks, the search has been unsuccessful.

The existence of coal at Wilgebosch Kloof[3] and Hartebeest Fontein, at the extreme eastern end of the high ground called the Komsberg, is said to have been known locally for 20 years or so, but attempts to follow up the discovery were first made about three years ago.

The coal at Buffel's Kloof and Leeuw River Poort occurs in fissures which are nearly vertical, so there is no difficulty in seeing at once that the coal does not form a bed or seam. At Wilgebosch Kloof and Hartebeest Fontein, on the other hand, the sheets of coal are inclined at a very low angle to the bedding planes of the sedimentary rocks, and their true relation to the latter would probably not have been recognized in the absence of artificial exposures.

The most work done has been done on the Wilgebosch Kloof coal, on which a tunnel about 430 feet long had been driven at the time of my visit. The section exposed in this tunnel is represented in Fig. 1. The fact that the coal occupies a fissure which cuts the bedding planes at an angle of about 5° can be verified in many places in this tunnel; though as the enclosing rock is a sandy mudstone of uniform character and with lamination not very strongly developed, and as the

[1] The Leeuw River coal is dealt with in the following Government publications;—E. J. Dunn, G.37—'79: and E. H. L. Schwarz, Annual Report Geological Commission for 1896: in the last-mentioned Report the occurrence is described fully.

[2] The Camdeboo occurrences are described in the following reports;—E. J. Dunn, G.37—'79: G.35—'83: G.8—'86. A. H. Green, Report on the Coals of Cape Colony, London, 1883. W. Molyneux, G.71—'81.

[3] Wilgebosch Kloof is in the Laingsburg Division, Hartebeest Fontein is an adjoining farm, but is in the extreme S.E. corner of Sutherland Division.

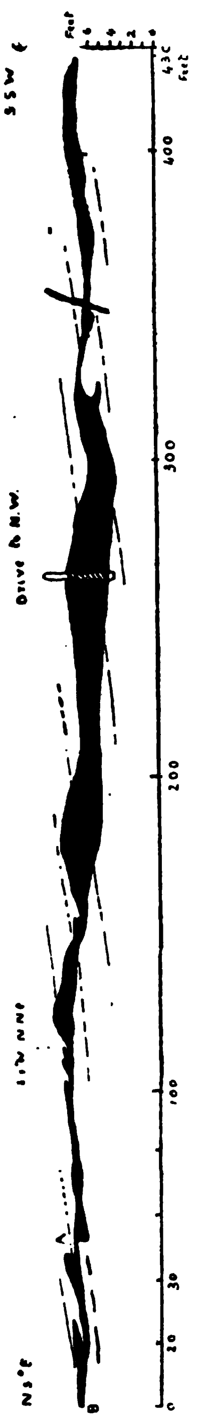


FIG. 1.—Section exposed on left wall of Tunnel on Wilgebosch Kloof. At A the roof has slipped northwards over the floor of coal. Entrance to tunnel at B

tunnel was driven approximately along the strike of the fissure, the relation of the latter to the bedding of the mudstone is not easily ascertained on the dimly lighted and dirty walls of the tunnel. The drive shown in the figure goes in a north-westerly direction, and is 30 feet long. In it the fissure is seen to slope in the direction of the drive, but the average true dip of the fissure is probably nearly W.S.W., though it changes slightly from place to place. The beds dip some degrees east of north.

Another tunnel has been driven 150 feet in a westerly direction near the mouth of the long tunnel. At the time of my visit the shorter tunnel was flooded and used as a source of water. It is inclined westwards as it follows the fissure into the hillside.

The Hartebeest Fontein fissure has been opened up by one tunnel about 60 feet long. This fissure crops out at a height of 560 feet above the Wilgebosch outcrop, and about three miles to the south-west. The opening is wider than that at the Wilgebosch Kloof, and a length 30 feet nearest the entrance can be studied in daylight, so that the details are readily seen. A sketch of the right wall, drawn to a scale, is given in Fig. 2. The beds dip at about 5° towards N. 8° W., and owing to the more laminated nature of the rock here, which is a sandy shale or mudstone, the relation of the coal to the bed-planes is more distinctly seen than in the Wilgebosch tunnel. The average northerly inclination of the coal is about 8°.

The two fissures are probably quite distinct at the surface, for no connection has been traced between them.

The Wilgebosch Kloof coal has been struck at 60 feet in a bore-hole to the west-north-west of the long tunnel entrance, and is said to have been 9 inches thick there.

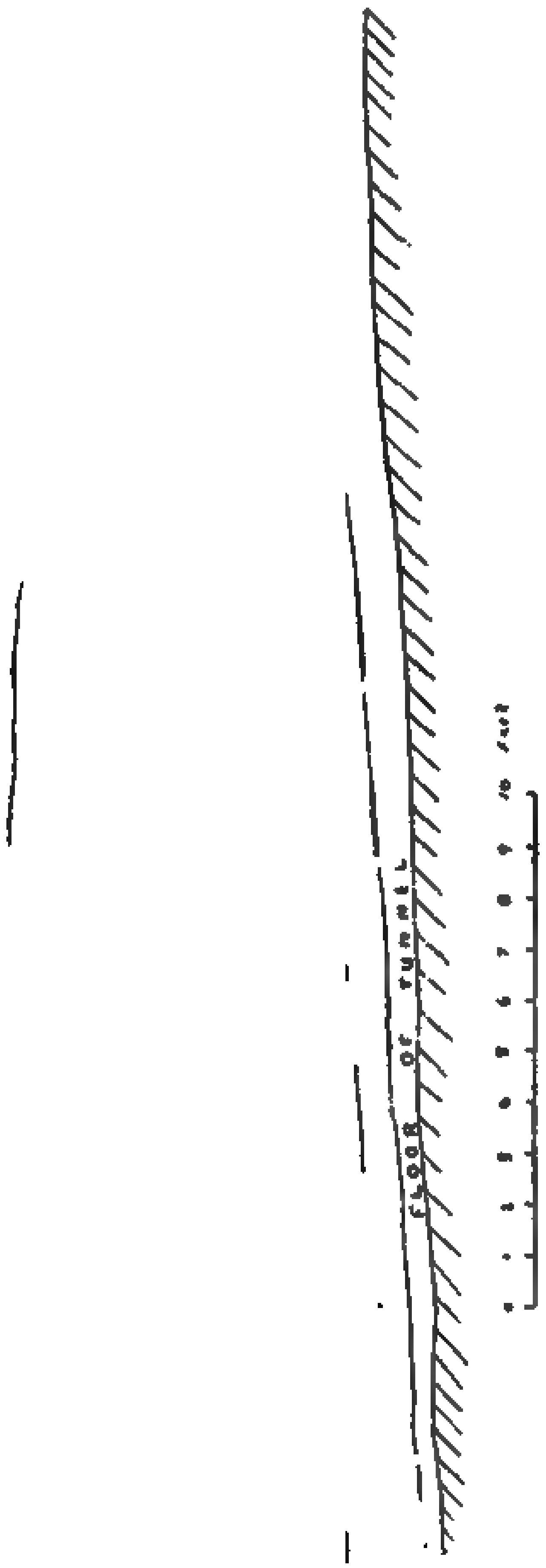



FIG. 2.—Coal veins seen in section on east wall of tunnel on Hartebeest Fontein. The broken lines indicate bed planes. At A, B, C are three slabs of the country rock in the coal. At D, E, F slickensides are seen on the roof of the vein. Vertical and horizontal scales are the same.

The general behaviour of the coal bodies is well shown in Figs. 1 and 2. The coal is a brittle and bright substance, and it keeps those characters to the surfaces of the country rock. Where the coal thins out to a mere streak it remains similar to the thick bodies in appearance. There is no intermingling of the debris from the sandy mudstone forming the country rock with the coal, but occasionally flat slabs of the country rock seem to be entirely surrounded by coal, as is shown in Fig. 2. In the long tunnel on Wilgebosch Kloof there are several short sheets of coal projecting southwards from the upper surface of the fissure, and in one case from its under surface. At the point marked A in Fig. 1, there is distinct evidence of the northward movement of the roof over the floor for about five feet, and the rock surfaces show slickensides there which must have been made by the friction of the two opposed rock surfaces

before the coal lay between them. The coal at this point presents the same characters as it does elsewhere, and it has not been crushed or rolled out there. At about 350 feet from the entrance there is a narrow dyke-like body of coal traversing the fissure, or departing from it both upwards and downwards, at a high angle. From the uniform character of the coal this dyke seems to have been filled at the same time as the fissure, and there were no apparent planes of separation between the two bodies of coal, that in the fissure and that in the dyke. In the Wilgebosch Kloof tunnel there are thin strings of coal branching out from the main fissure in the same way as at Hartebeest Fontein, but owing to the difficulty of seeing them throughout their length by the aid of a candle they were omitted from the measured section which is reproduced in Fig. 1.

Slickensides were seen in the Hartebeest Fontein rock, and their positions are indicated in the section. They are not present over many parts of the roof, and were not seen on the floor of the thickest part of the coal. From the position of single bed-planes it is clear that the relative movement of floor and roof in this locality could not have exceeded an inch or two.

The coal at both these localities has a peculiar structure owing to the presence of innumerable slightly rippled surfaces, along which it breaks easily, usually inclined at a high angle to the roof or floor; they are often curved, and by their intersection they give rise to wedge- and cone-shaped pieces of coal with a flat base. The coal has thus a kind of cone-in-cone structure. No trace of lamination parallel to the walls of the fissure was detected. The general impression given by the manner of occurrence of the coal is that it reached its position by means analogous to those which brought about the deposition of the quartz in massive veins without successive layers due to gradual deposition on the walls of the fissure. Such quartz veins are frequently seen in granitic regions. It is evident from the character of the coal and its freedom from comminuted country rock, as well as from the details of the fissures, that no process of faulting can account for the phenomena; also that there is no question of cracks on an old floor of deposition being filled with coaly matter during the formation of a coal bed on that floor.

The figures of the analyses of the coal are peculiar; they show low percentages of ash, usually much water, and high figures for "volatile matter." Three analyses have been

made in the Government Analytical Laboratory, and Dr. C. F. Juritz kindly gave me the figures, which are :—

| | i. | | ii. | | iii. |
|---|---|---|---|---|---|
| Ash .. .. | 6·93 | .. | 7·83 | .. | 2·144 |
| Moisture .. | 14·99 | .. | 2·02 | .. | 7·46 |
| Volatile hydrocarbon | 24·81 | .. | 23·5 | .. | 13·3 |
| Fixed carbon | 53·27 | .. | 68·7 | .. | 76·2 |
| Sulphur .. | ·58 | .. | 1·83 | .. | ·865 |

i. and iii. from Wilgebosch Kloof, by J. G. Rose and G. F. Britten respectively.

ii. from Hartebeest Fontein, by G. F. Britten.

Two other analyses of similar character may be quoted, one of a coal from the Leeuw River Poort fissure given in Prof. Schwarz's report of 1896, and the other of the Lange Kuil coal[1].

| | iv. | | v. |
|---|---|---|---|
| Ash .. .. .. .. | ·80 | .. | 6·86 |
| Moisture .. .. .. | ·68 | .. | 14·31 |
| Volatile matter .. .. | 19·01 | .. | 28·79 |
| Fixed carbon .. .. | 80·19 | .. | 50·04 |

iv. From Leeuw River Poort, by the late Mr. Watermeyer.

v. Lange Kuil, by Mr. J. G. Rose.

The chief differences between the figures obtained from these coals and the analyses of other South African coals are the low amounts of ash, the usually high figure for water, and the large proportion of volatile hydro-carbons. The divergence between the analyses i. and iii. from Wilgebosch Kloof is remarkable ; they are different kinds of coal ; particulars of the exact spots whence they were obtained are not available.

The occurrence of the Lange Kuil coal is described in the Report for 1903. In physical and chemical characters it is like the fissure coal, but it appears to be interbedded with the sediment amongst which it is found. Another visit was paid to the locality to confirm or correct the statements made in the report referred to. No further prospecting work had been done, and the exposures had naturally suffered during the six years' interval, but so far as the facts could be ascertained, the coal forms a bed. It is possible that it is really a fissure running parallel to the bedding over the area exposed ; but there is no evidence for this view in the occurrence of small veins given out upwards or downwards from the layer of coal, and such a parallelism over 60 feet, as is seen at Lange Kuil, is not seen in the Wilgebosch Kloof or Hartebeest Fontein exposures.

[1] Annual Report Geological Commission for 1903, p. 34.

The important point about the fissure coals is that they are not ordinary coals either in composition, physical characters or mode of occurrence. The most prominent fact connected with their occurrence is that they are found near the southern limit of the great intrusions of dolerite, and it seems impossible to avoid the conclusion that the dolerite intrusions are in some way responsible for them.

The explanations of the occurrences have been various. In Mr. Dunn's first report on the subject (G.37—'79, p. 31), the production of the fissures in the Camdeboo and at Leeuw River Poort was attributed to disturbances which accompanied and followed the rise of the intrusive and volcanic rocks of the Karroo region, and the coal itself was supposed to having faulted up to its present position from some horizon in the Ecca beds below the fissures. The low ash-content of the coal, however, is alone sufficient to condemn this explanation. In a later report (G.35—'83), after borings had been made in the Camdeboo, Mr. Dunn abandoned this explanation and attributed the presence of the fissure coal to the action of the dolerite on carbonaceous shale in the Karroo rocks (G.35—'83, p. 4). In a third report (G.8—'86), Mr. Dunn returns to his earliest solution of the question, and considers that the "singular outcrop of coal at Buffels Kloof appears to be a distinct proof that valuable coal deposits exist in this basin," and that "the masses of pure coal and shale are a portion of this black shale belt [part of what is now called Upper Dwyka shales] well in from the margin, and an actual sample of what exists below." The question of how such pure coal could remain uncontaminated with rock powder which would be produced in the process of faulting is not considered.

Mr. W. Molyneux, who examined the Leeuw River Poort and Camdeboo occurrences, came to the conclusion that the coal had been washed into fissures from above, at the time when the Stormberg coals were being formed; that its purity is due to selective washing by water at that time, and that the effect of the dolerite intrusions was to convert the material in the fissures into the "anthracite" found there now. (G.71—'81.) Prof. A. H. Green, who visited the Camdeboo in 1882, considered that the coal had "been introduced mechanically," and that the fragments of coal had been welded together, thus enclosing fragments of the country rock, by great pressure. No mention is made of the difficulty in explaining the absence of powdered rock from the coal.[1]

In 1896 Prof. Schwarz examined the Leeuw River Poort coal occurrence very carefully, and at that time the now

[1] A. H. Green, Report on the Coals of Cape Colony, 1883, p. 26.

abandoned workings were in a condition to be explored. His work did not lead to any definite explanation, but he remarks: "I do not think it [the coal] has been faulted into its present position."[1] In the prospecting work a hard bed of sandstone "riddled with thin horizontal seams of coal about an inch thick" was met with. These thin seams were apparently not examined with a view of ascertaining whether they are identical in composition with the fissure coal; it is possible that they are really small fissures formed parallel to the lamination of the sandstone, and filled from the same source as the main fissure. The sandstone was met with at the bottom of the last shaft sunk. In a later report[2] Prof. Schwarz, on seeing a vein from a coal seam traversing sandstone in Maclear, in the neighbourhood of a dolerite dyke, suggested that the coal was carried to its present position by heated water.

Though the coal at Wilgebosch Kloof and Hartebeest Fontein behaves very much in the way that vein-quartz does in certain cases, there is a difficulty in understanding how such a substance could behave as a liquid under the influence of heat; for at any rate at atmospheric pressure the coal separates into several parts when heated out of contact with air. It may be that the conditions of pressure obtaining at the time allowed the substance to be liquified. If the coal reached the fissures at the time of the intrusion of the dolerite the pressure must have been very considerable, for the present exposures were laid bare by the removal of at least 3,000 feet of rock, probably very much more, by denudation since the intrusion took place.

The solution of this problem would, of course, answer the question of the commercial value of the neighbourhood as a source of coal. The only way which seems likely to lead to a solution is the full exploration of one of the fissures by tunnelling along it to find out what it leads to. Drilling holes at random on selected sites, as has indeed been done in the Camdeboo, will only be successful if there are workable seams underneath, and this, of course, is not known; but from the considerations given below, their existence is very doubtful. If at any time the value of the coal obtained during the expensive exploration should be such as to repay a substantial part of the cost, the work will be worth undertaking, but at present this is not the case.

The details of the veins on Hartebeest Fontein are such as to give the impression that the source of the coal was to the

[1] Ann. Rep. Geol. Com. for 1896, pp. 24 & 25.

[2] Ann. Rep. Geol. Com. for 1902, pp. 16 & 17.

north of the outcrop, *i.e.*, within the hillside. At Wilgebosch Kloof the evidence is less clear.

The country near the two coal localities described above is very well adapted for prospecting, so far as the exposures of the rocks are concerned. The steep escarpments of the Komsberg and the Nieuweveld offer innumerable exposures in spite of the débris which conceals the softer beds over large areas of the slopes. The rocks which lie below those in which the coal fissures occur are very well seen in the western part of the Gouph, the Moordenaar's Karroo and the dissected range of hills between them. If coal of any value exists in the rocks of the escarpments or those of the Great Karroo to the south, it is probably in a seam or seams which extend for some distance. It is very unlikely that there should be seams of any worth which are everywhere hidden at the surface, or which never crop out on account either of original want of extension or partial destruction by contemporaneous denudation. Evidence of contemporaneous denudation within the Beaufort and Ecca beds is very frequent in the regions north and south of the escarpments, but that any one such unconformity should affect a particular band of rock over a very wide area is extremely improbable.

The fact that the discoveries of coal on the escarpment which have been prospected since 1875 have all proved to be of the same curious kind shows that it is very unlikely that seams exist on that escarpment itself.

There is some similarity between the occurrences of the peculiar coals in the Nieuweveld region and that of asphalt minerals in veins in the Uinta basin and other areas in the United States,[1] but there is also the great difference that in the latter region the veins are not associated with intrusive rocks.

## The Dolerites.

The very numerous intrusions met with in the northern half of Beaufort West, Fraserburg and Sutherland belong to the group called the Karroo Dolerites. Though almost the whole of the rock is dolerite, either with or without olivine, small veins and masses within it consist chiefly of quartz and orthoclase felspar. It is rarely that one of these acid rocks occurs outside a sheet of dolerite, and they obviously belong to the same great group of intrusions as the dolerites themselves.

[1] Twenty-second Annual Report of the U. S. Geol. Survey, vol. 1, G. H. Eldridge. The Asphalt and Bituminous Deposits of the United States.

A full description of the distribution of the dolerites would be tedious, and it is unnecessary. The recently published Sheet No. 13 of the Geological Map represents a large part of the area described in these pages, and on it the general distribution of the dolerite can be seen. The work done on the dolerites in this area is a continuation of that begun in 1896, 1902 and 1903[1].

The dolerite occurs in dykes and sheets, names given to bodies of the rock that cut through sedimentary beds at high angles and low angles respectively. The distinction between the two forms of intrusion is obvious enough in most cases, but there are several bodies which might be given either name. These will be classed as inclined sheets in this Report.

By far the greater bulk of dolerite visible at the surface is in the sheet form, and, with few exceptions, the sheets seen were thicker than the dykes. The sheets are often over 100 feet thick, occasionally exceeding 300 feet, but the vertically placed intrusions are rarely over 300 feet wide, usually from 10 to 20 feet. It is the case, however, that unusually thin sheets are very liable to escape notice during a rapid survey. Extremely thin sheets, those which do not exceed two or three inches in thickness, weather very like thin sandstones. Such sheets were seen in the cliffs on Hoedemarker's Kraal and the southern part of Albert's Graf. They have a dull grey crust with small specks caused by small felspar and augite crystals, and they give rise to no feature which attracts the attention. Thin dykes, on the other hand, generally make a feature owing to the fact that moisture lies near the surface along them and promotes a rather more abundant growth of bush there than elsewhere. Dykes that are not more than a foot thick certainly have this effect.

Approaching the Nieuweveld from the south one gets the impression that dykes are comparatively scarce forms of intrusion in this region. The great dolerite cliffs of the escarpment make such striking features in the landscape that the importance of the dykes in the country below escapes attention. The sheets continue to dominate the landscape for some 20 or 30 miles to the north of the escarpment, but they are less extensive, or at any rate they present fewer and shorter continuous cliffs in that area than further south. In the northern parts of Beaufort and Fraserburg, and the southern part of Carnarvon the dykes become more conspicuous, and the sheets diminish in frequency and thickness.

[1] Ann. Rep. Geol. Com. for 1896, pp. 18-24; Ann. Rep. Geol. Com. for 1902, pp. 121-126; Ann. Rep. Geol. Com. for 1903, pp. 36-43.

Though in many places in the northern part of the district comparatively thin sheets are given off from dykes, great thick sheets like that of Bulthouder's Bank and the dissected sheet crowning the mountains between the Oude Kloof and Thee Kloof roads to Fraserburg are not seen.

The sheets rarely remain at the same level over large areas; they have either a gentle and uniform slope or are inclined sharply along a fairly well defined line. The inclination in different parts of one and the same sheet is in various directions, so that the outcrops make great curves; in the case of some sheets the result is very similar to the basin-shaped intrusions described by Mr. du Toit from the Queenstown district.[1]

As an example of the behaviour of one of the larger masses of dolerite in the district a brief description of the sheet which crowns the Nieuweveld to the north-west of the town of Beaufort may be given.

It commences on the east on the boundary of Alwyn's Gat and Bok Kraal, in contact with a thick inclined dyke which runs north-eastwards through Rhenoster Fontein. This dyke, which slopes very steeply to the north-west, may perhape be a feeder, but it can hardly have been the main source of supply. The sheet forms a wide area on Bok Kraal, Pieter's Vley, and the southern part of Groote Vley, and an outlier has been cut off by the two head streams of Zak River which rise on the edge of the cliffs on either side; this outlier is called Bulthouder's Bank, and on it stands the Trigonometrical Station of that name, 6,271 feet above the sea and 3,480 feet above Beaufort West town; it is the highest point on the edge of the Nieuweveld, though exceeded by other areas to the north-west and north-east. The sheet is rather over 300 feet thick at the edge of the Nieuweveld, and it is inclined northwards at a slightly higher angle than the dip of the bed it rests on, so that it cuts through these. The Zak River has excavated a fine gorge about three miles long in the sheet, and the dolerite on each side rises as much as 300 feet from the river bed. Further west the sheet becomes thinner, and the streams flowing north from the back of the escarpment have cut their way down to the sedimentary rocks below or have exposed inliers of the latter owing to the shape of the uneven lower surface of the sheet. This dolerite area ends abruptly along a line which runs a few degrees north of east, from west of Paarde Kraal to the Rhenoster Fontein ground; from the facts that the deep valleys make no change in the direction of this line, and when they

[1] Ann. Rep. Geol. Com. for 1905, pp. 132-136.

leave a shale inlier or deep embayment of the southern edge of the sheet, as at Paarde Kraal, where there is a section through an apparently nearly vertical mass of dolerite, it is evident that the thick sheet bends down abruptly and assumes the habit of a dyke, as is represented in the section drawn through Sheet 13.

From the neighbourhood of Paarde Kraal the southern edge of the sheet turns north-north-west, making a great cliff overlooking the head of the Sand River valley in the Gouph. The sheet along here is inclined north-east and eastwards, but it gives off a thinner sheet at the north-west corner of Paarde Kraal. This second sheet rises through higher beds of the Beaufort series and striking eastwards forms an irregularly shaped area about nine miles long between its point of origin at the surface and Rhenoster Fontein. It is inclined to the north, but it has apparently given rise to a nearly horizontal sheet at a higher level than its present outcrop on Groote Vley, Klaver Vley and Wittehart. The conspicuous detached table mountain on Klaver Vley, which rises some 300 feet higher than Bulthouder's Bank, may be an outlier of this sheet.

The north-north-west, striking part of the main sheet, is continued for about 11 miles to the north-eastern beacon of Matjes Valley (the western of the two farms of this name on the southern Nieuweveld), but it turns abruptly eastwards and crops out over a wide area on Bastard's Poort, Middel Kraal and Waterfall. The Trigonometrical Station, Bastard's Poort, 6,034 feet, stands on the northern edge of this part of the sheet. The inclination of the sheet is to the south in this area, and for some five miles the southern limit is an almost straight line, in spite of the deep kloofs across it; where the Zak River crosses it, the "sheet" is evidently a dyke with high inclination to the south, just at the northern boundary of the Paarde Kraal and Bok Kraal portion of the sheet is a dyke. From the Zak River gorge in the dyke, the dolerite stretches north-north-east to Leeuw Kloof and Bult Fontein, in the form of an easterly-inclined sheet with very irregular boundaries, and from Leeuw Kloof it also goes north-westwards to form the great sheet of Rapuis Berg and Gert Adrian's Kraal, 24 miles north of the dyke on the Zak River. On Snyder's Fontein it is continuous with the great curved inclined sheet of Kaffir's Kraal.

An examination of the map (sheet 13) will show the intricate relations between the Bulthouders Bank sheet and a great part of the dolerite lying to the north. It would be possible to walk from the cliff formed by this sheet above Beaufort West

far into the Victoria West, Fraserburg or Carnarvon Divisions without stepping off the dolerite.

In the section drawn through sheet 13, a direct underground connection is shown between the Bastard's Poort and the Bulthouder's Bank portions of the sheet; this is, of course, hypothetical, though all the evidence points to the existence of the connection.

The numerous inclined sheets found some distance north of the Nieuweveld escarpment generally make great curved outcrops. They are well exemplified by the Kaffir's Kraal sheet, which is in direct connection with the Rapuis Berg sheet on the east. The dolerite makes a prominent ridge, with an extremely steep escarpment on the outer side of the curve and a less steep surface on the concave side towards which the sheet is inclined. For some 25 miles from Rapuis Berg the dolerite outcrop is comparatively narrow, though on the south-west boundary of Snyder's Fontein it is widened by a thin

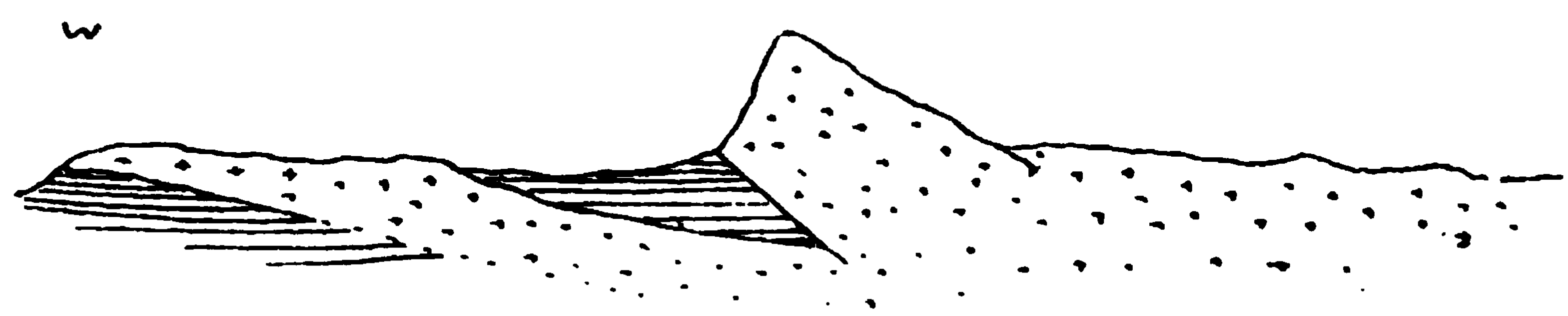



FIG. 3.—Section one mile long through the beacon hill of Kaffir's Kraal Berg. Vertical and horizontal scales the same.

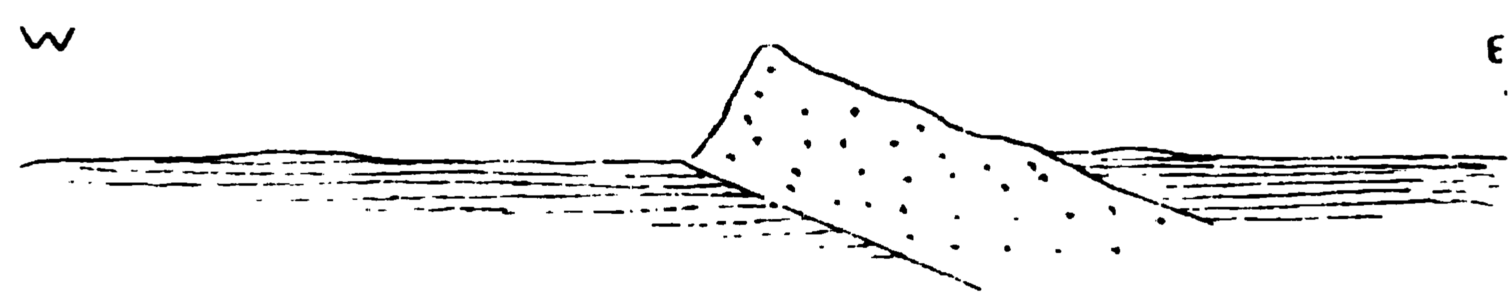



FIG. 4.—Section one mile long through the inclined sheet of Kaffir's a mile south of that in Fig. 3.

sheet given off horizontally from the inner side of the curved inclined sheet. On the south of the farm Kaffir's Kraal a thick sheet is given off on the escarpment side, and further north the inclined sheet either becomes horizontal at a higher level than usual or else it gives off a thick sheet on the inner side of the curve. (See Figs. 3 and 4.) This sheet covers some nine square miles, and has the usual hummocky, rough surface that this rock gives rise to, and it is bounded on the north-west by the steep ridge formed by the inclined portion of the sheet, Kaffir's Kraal Berg, on which stands a conspicuous beacon at about 5,500 feet above the sea and 800 above the

dolerite sheet on the inner side of the curve. Further north-west the inclined sheet forms a comparatively narrow outcrop for some eight miles, and then, on Spring Fontein, it either becomes a horizontal sheet or else gives off such a sheet at a high level, which hides the steeply-inclined portion of the sheet for some 12 miles, but beyond Bies Berg it is again met with in a conspicuous ridge which was followed past Slang Fontein into the Victoria West Division. East of Bies Berg the sheet is inclined northwards, and the outcrop makes a great curve concave to the north-west.

Changes in the direction of inclination, of which a conspicuous example has just been given, are frequently met with in the district surveyed last year; in cases where the inclination is not high, say, less than 15°, these changes of direction give rise to rather puzzling relationships between the sheet and the sedimentary rocks. As one follows the boundary of a dolerite escarpment in such a case, with the dolerite clearly resting on the sedimentary beds, one becomes aware that the dolerite breaks across the beds and passes under them, while the escarpment has to be looked for on the far side of the sheet. The change takes place very gradually in some cases, and the dolerite débris obscures the actual junction, so that the result is difficult to understand at first.

The best example of a clearly defined and completely closed curved inclined sheet is the one on Kaffir's Kraal (a farm lying 18 miles south-east of the Kaffir's Kraal mentioned above). It is at the most only four miles wide from an outer escarpment to the opposite one; the interior is occupied by a terraced circular area of sandstone and shale, and this is surrounded by a steep slope of dolerite, which has a precipitous face on the escarpment facing the surrounding plains. At two places small sheets are given off on the outer side. The highest part of the dolerite is called Vissers Kop, which rises about 850 feet above the flats outside the ring. The Zak River has cut through this ring of dolerite, though from the present contours of the area it looks as if the river would have found a much easier path just to the west of it. Probably the river took its present course before the curved sheet was completely exposed at the surface.

A curious case of want of continuity of a steeply inclined sheet is offered by the sheet which stretches north-east from near Steenkamp's Poort to Klip Kraal and Kalk Fontein. If is inclined north-west, but becomes flat on the south-east side and bears two large outliers of shale on its surface. At Klip Kraal the dolerite outcrop stops before it reaches the river bed, but it appears again on the opposite side of the valley,

where it again seems to be a steeply-inclined sheet. Where the Bloemfontein River crosses it south of Dams Fontein it is a thick sheet inclined northwards.

On Abram's Kraal there is an interesting case of an interruption of outcrop of a dolerite dyke. The dyke runs E.35°S. across the valley west of Abraham's Kraal homestead into Paarde Berg, and is apparently continued on the east of the mountain by a dyke going E.15°S. The outcrop west of the mountain is interrupted along a distance of some 300 yards, but in that gap there is an "aar," along which the shales and thin sandstones are raised into a simple anticline about 15 feet wide with its axis on the line joining the two dolerite outcrops. The anticline is exposed in a shallow well, and the beds are seen to be much broken and closely jointed, but there is no dolerite in the section. This is clearly a case in which the upper edge of the dyke is very uneven, for there is a difference of several hundred feet between the levels of the valley where the dolerite does not reach the surface, but lies underground, and of the position of the highest outcrop on the flank of Paarde Berg.

The thin vertical dykes which are so abundant north of the escarpment rarely have straight courses for many miles, though they are usually much less frequently curved than the great inclined sheets. The longest of these dykes seen is the one which can be traced from the north edge of the outcrop of the great sheet to the south of Groote Vley for about 23 miles past Dunedin to Leeuw Kloof. It is only from 5 to 10 feet wide and outcrops are not often seen, but the line of bush on its course makes it easy to follow. Where it should traverse a sheet it is lost sight of, though in the case of a few dykes they can be followed easily across a sheet because they have weathered out more rapidly and uniformly on steeply sloping ground than the coarser work of the sheet; a good example of this is to be seen from the road on the north face of the Bastard's Poort sheet near the high beacon.

Where clear surfaces showing the junction of thin dykes and the larger intrusions were found, the dyke is always the later rock. On Bok Poort, Quagga's Fontein and Klip Heuvel contacts of dykes exposed in the beds or ravines showed finer grained margins in the dykes, just like the margins seen at the contacts with sedimentary rocks. This fact shows that the thin dykes referred to are distinctly younger than the sheets they traverse, which must have been cold at the time. Evidence of this kind is not easily obtained, for one usually has to search carefully for a suitable exposure, and on a rapid survey this takes too long a time where the

dykes are too numerous to be shown in many cases. The probability is that a large number of the thin dykes are later than the sheets.

The thin dykes lie in all directions, though courses lying between N. 10° W. and N. 30° W. are more often seen than others. The main joints in the sedimentary rocks throughout this area lie between N. 5° E. and N. 20° W., and there does not appear to be any evident connection between the courses of the dykes and the joints. It is probable, however, that the joints have really determined the direction of the dykes, but that the dykes frequently break across from one joint to another parallel to it and a few inches or feet distant from it by passing along a joint belonging to another group. or along bed planes. That this does happen is proved by outcrops of a thin dyke to the east of the road 2 miles south of Dunedin. The dyke, which is three feet thick, is clearly exposed along 180 yards of ground where the joints are also seen, but the dyke is discontinuous at the surface. The result is that though each part of the outcrop is parallel to a joint system the average direction of the dyke is several degrees away from it. Small irregularities of this kind may, of course, turn the dyke in any direction.

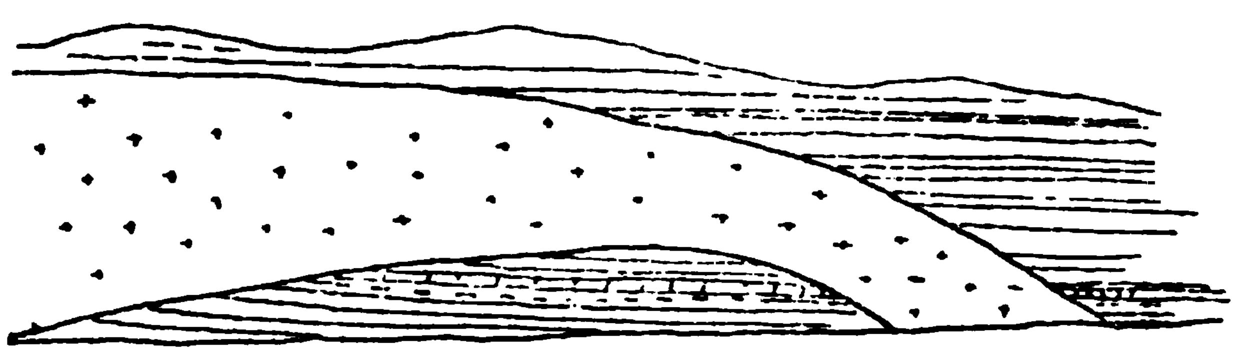


FIG. 5.—Diagrammatic sketch of a part of right bank of river on Onder Plaats (part of Groot Fontein), in Fraserburg, showing the rise of an inclined sheet through thinly bedded shales and sandstones. The length of the section is about 500 feet.

A most striking feature in connection with the dolerite intrusions is the very slight disturbance of the sedimentary rocks round them. The only marked tilting of the strata is to be seen on each side of some of the thin dykes, where dips of 15° or 20° are occasionally found at the immediate contact. An equally great tilt was not noticed at any contact of the thick sheets. On the west side of the steeply inclined (towards the east) sheet cut through by the Zak River on Zaai Fontein there is a low easterly dip traceable for as much as 300 yards from the dolerite, but this was the only case where a noticeable local dip was found along a great intrusion.

It is rarely that a clean-cut section illustrating the absence of disturbance in both over- and underlying beds is found, but a good one was met with at Onder Plaats in Fraserburg, where a thick sheet rises through shales and thin sandstones in the manner shown in Fig. 5. The thickness of the sheet increases to at least 300 feet turther west, but the base is not seen there. The underlying beds are only exposed along 140 yards of the river, but neither they nor the overlying beds show any noticeable bending. A good illustration of the same phenomenon in the case of a thin offshoot from a large inclined sheet on Abram's Kraal is shown in Fig. 6. The rocks are clearly exposed, and even where the dolerite has a very irregular surface and projects at various angles from the usual limits of the sheet no sign of pushing-aside of the shales is seen. The dolerite sheet ends bluntly in the shales on the west (right hand) side of the section.

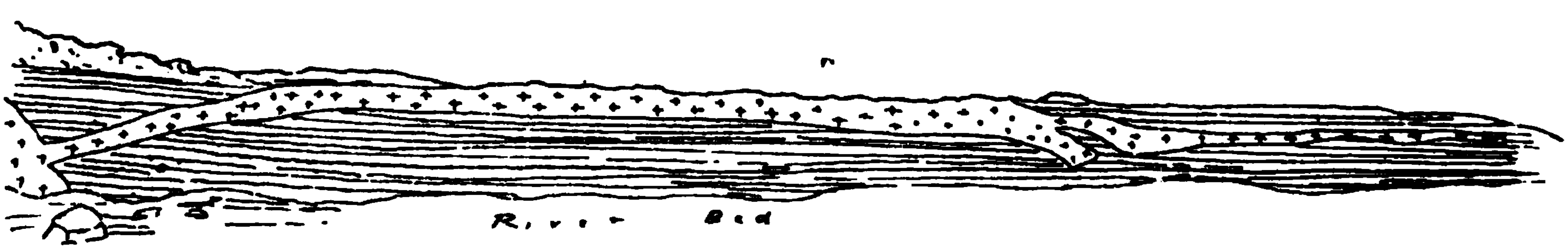


FIG. 6.—Sketch of a thin offshoot of a large sheet on Abrams Kraal (Victoria West) seen in section on right (south) bank of river bed above the farm house. The length of the section is 95 yards. Vertical and horizontal scales are the same.

A good section through the northern margin of the thick sheet of Albert's Graf and Klip Heuvel in Fraserburg is seen in the river bed above Fliege Kraal house. It is represented in Fig. 7. The dolerite becomes finer-grained than usual at a distance of three feet from the margin, and at the contact is a very fine grained black rock in which the constituents are not visible to the naked eye. The sediments are hardened within two or three feet of the dolerite, but their lamination is quite regular and abuts against the dolerite without the least deflection. Numerous close-set joints have developed in the shales and thin sandstones seen in the section within five feet or so of the dolerite. These joints are inclined steeply southwards towards the dolerite, but they are not parallel to the surface of contact.

Another clearly exposed section through the margin of a great sheet is exposed near the edge of the cliffs S.S.E. of Van Rhyn's Plaats in Fraserburg. The dolerite forms a sheet which caps the escarpment above the Gouph in this neighbourhood, and the section is to be found in a short kloof from which the water in wet weather falls several hundred

feet at a point some 200 yards further down than the place where the section (Fig. 8) is seen. This sheet is an inclined mass of dolerite of considerable thickness, over 400 feet at this part, and about four miles to the east it gives off a thick sheet towards the Gouph (Riet Fontein, Michau's Request, Kaffir's Kraal Hoek, etc.) and a steeply inclined sheet to the north, of which the outcrop maintains a high level. At the place where the section in Fig. 8 is exposed the northern surface is very irregular, and a thick but short offshoot is

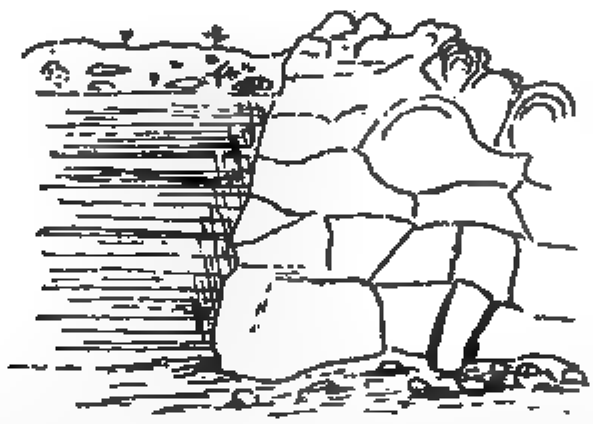


FIG. 7.—Sketch of dolerite—shale junction on Fliege Kraal, Fraserburg, on right bank of river. Section is 15 feet high. The dolerite is the north edge of the Alberts Graf sheet. The shales are closely jointed and hardened at the contact.

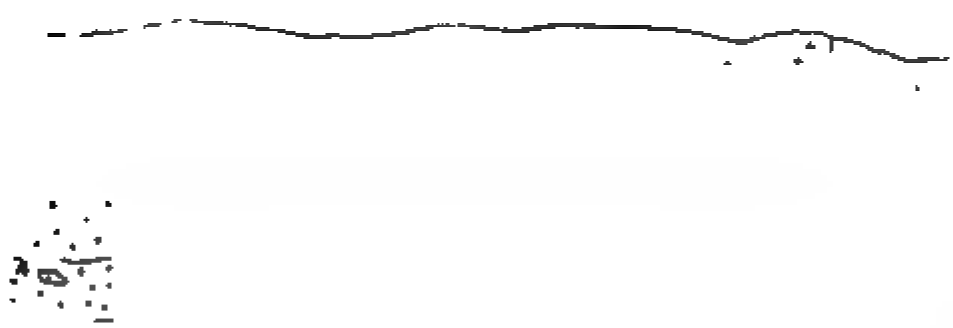


FIG. 8.—Diagrammatic sketch of right bank of kloof S.S.E. of Van Rhyns Plaats, Fraserburg. Length 150 feet, height 45 feet. Section through north edge of a thick inclined sheet (inclined northwards towards the right), which here has an irregular surface.

shown in the figure. Though the dolerite limit is so uneven the sediments abut against it without deviation from their usual dip, which is here at a very low angle towards the north or north-north-east; they are practically flat over short distances. At A in the figure is a pale coloured acid patch embedded in the dolerite, which is shown passing northwards under the bed of the stream.

## PETROGRAPHY OF THE DOLERITES ETC.

There is a general uniformity in character in the dark coloured intrusions in this area; the rock in thin bodies differs much from specimens taken from any part but the margins of the large bodies, but the marginal portions of the great sheets and dykes are practically identical with the rocks of the thin dykes and sheets. The chief constituents are labradorite, augite, olivine or serpentinous pseudomorphs after that mineral, ilmenite and magnetite, biotite, green hornblende, quartz and orthoclase. The only section cut from one of the larger intrusions mapped last year came from Van Ryneveld's Kop on the farm Welgevonden on the northern border of Beaufort West district. The augite is in large masses enclosing the felspars, and there is a little olivine, biotite and magnetite. This rock resembles closely that forming the large sheets of the Nieuweveld, of which several slices were cut after Prof. Schwarz mapped them in 1896. Some slices are without olivine, and in these the green hornblende and quartz with orthoclase are generally seen; the quartz and orthoclase always occur together as micropegmatite. There are sections, however, such as (2512) from a thick sheet on Tafel Berg (on Riet Fontein, Fraserburg) in which the micropegmatite is found along with serpentine and magnetite pseudomorphs, apparently after olivine.

A remarkable variety of dolerite was noticed apparently forming a small outlier of a sheet of ophitic dolerite on Spinnekop's Kraal, in Fraserburg. If this view is correct the peculiar rock must have lain at the base of the ophitic dolerite, in contact with sedimentary rock. The supposed outlier is about 500 yards long, in a S. 10° W. direction, and 200 wide. On the outcrop it looks like a glassy rock with very large spherulites. In thin section (2513) a specimen from one part of the outcrop is seen to be made of bunches of felspar crystals, often of the "skeleton" form, arranged in a rather confused manner, so that neighbouring bunches interfere with each other; between the radially arranged felspars there are immense numbers of small granules of augite and magnetite in a glass basis, and the augite granules extinguish simultaneously over small areas, so that there is an incipient ophitic structure. Parts of the slice have a more dense and finer grained arrangement of the augite and felspar than others. A specimen from another part of the same outcrop (2514) shows an advance in the size of the components and in their state of crystallization; the felspar crystals (labradorite) are well formed, and the augite occurs in large wedge-shaped areas between them. There is some devitrified glass in the slice.

This peculiar rock reminds one of the descriptions of the variolitic modification of diabase. If it were of frequent occurrence in this region it would be noticed readily, for the spherulitic bunches, ofted half an inch across, give the outcrop a characteristic appearance.

Two slices were cut from a thin sheet on Hoedemaker's Kraal (2533 and 2534), where the sheet is two inches and half-an-inch thick respectively. The outcrops are at a distance of several hundred yards from the nearest visible large mass of dolerite, which is a thick inclined sheet. The matrix of the rock is a very fine-textured felted mass of minute felspar microlites with tufts of a chloritic mineral and some carbonate; in this are set crystals of labradorite reaching a length of 1mm. and augites about half that size. The augites have good crystal forms, but occasionally a labradorite crystal projects into a crystal of augite. There are also small pseudomorphs of carbonates containing grains of magnetite and strings and patches of serpentine; these probably represent olivine. The labradorites are arranged parallel to the surfaces of the sheet when they lie within a tenth of an inch or so of them.

The fine-grained margin of a sheet on Bok Poort (2627) has a structure and constitution just like that of the Hoedemaker's Kraal rock. The fine-grained margin of a dyke on Esterville (2631) is a very similar rock, but it has a number of small green pseudomorphs made of a highly birefringent mineral, like a green biotite, which may represent olivine or augite. The edge of a thick sheet on Van Rhyn's Plaats shows a different structure from any of the above. The augite and labradorite crystals lie in a very fine-grained granular matrix of augite, felspar and magnetite.

The dykes of moderate thickness, from three to 20 feet, usually have the ophitic structure well developed, but on a smaller scale than that found in the great sheets; a dyke on Quagga Fontein (Victoria West) shows a different structure. This dyke is about 30 feet wide, but it makes a remarkably small feature for so large a dyke. It consists of labradorite, augite, devitrified glass, magnetite and a very little biotite. Though it is a coarse rock, the augite only occurs in irregular wedges between the labradorite, and not in ophitic masses. The magnetite is arranged in strings having the form of skeleton octahedra.

Pale-coloured acid rocks were met with in close association with the dolerite in many parts of the district. It is rarely that they occur isolated in the sedimentary rocks; though

possibly there may be more of them so situated which have escaped notice through similarity of their appearance to a weathered sandstone.

On the northern slope of Tafel Berg on Riet Fontein, in the Fraserburg Division, there is a good exposure of the top and bottom of a thick inclined sheet, capped by a thin layer of shales and sandstone. The sheet is 600 feet thick, as measured between the outcrops of sedimentary rock, but it may be thinner than that actually, for the sedimentary rocks are not exposed in a vertical section, so that a change in the inclination of the base of the sheet would affect the thickness. About half-way up the slopes there is a sheet of pale rock, six feet thick, and it was traced for 80 yards along the outcrops. The contacts with the dolerite are quite sharp. Thin sections of the pale rock (2510, 2511) show it to be chiefly made of long crystals of an oligoclase felspar embedded in a micrographic intergrowth of quartz and orthoclase, with a little epidote, magnetite and sphene, and rather much chlorite, apparently replacing biotite. In places the chlorite forms long sections, but whether biotite or hornblende was the original mineral could not be determined. The felspars in this rock, as in all the specimens of the acid rocks examined are very cloudy.

Usually the acid rock forms narrow vertical dykes in the dolerite; such dykes were seen on Tabaks Fontein, Elands Fontein, Vaal Water, and Albert's Graf. The Tabak's Fontein rock (2509) consists of quartz and orthoclase with a little plagioclase, chloritized biotite and epidote, and minute bunches of sericite flakes. The structure is micrognanitic and there is no micropegmatite. The rocks from Vaal Water, Albert's Graf and Eland's Fontein are very similar to the above, and vary chiefly in the amount of the sericitic mica present. None of them have well developed micropegmatite.

On Fliege Kraal, in Fraserburg, there are two masses of acid rock projecting from a hill-side made of dolerite. The largest mass is 200 feet long and about 30 wide. The acid rock evidently resists the weather better than the dolerite enclosing it, and also better than some small lumps of dolerite enclosed by it. It is a grey rock with many drusy cavities lined with the projecting ends of quartz and felspar crystals. The contacts with the dolerite are sharp. The rock varies considerably in texture, and the finer grained kinds form irregular veins in the coarser. In thin section (2650) is a fine-grained micropegmatite of quartz and orthoclase with some chlorite, apatite and thin plates apparently of ilmenite.

On Aya's Fontein there is an irregularly shaped outcrop

of an acid igenous rock projecting from an alluvial flat within about 30 yards of the north edge of the Aya's Fontein dolerite sheet. On one side it is in contact with sandstone, and it looks just like a hardened portion of the latter in the field. The outcrop of the acid rock is about 100 yards wide and rather more than that at right angles; it has drusy cavities and some oval patches of rather dark rock, and it weathers into great rounded boulders like those formed by the harder beds of sandstone in the Beaufort series under certain conditions. The lighter coloured part of the rock is seen in thin section (2535) to be a fine-grained micrograniitic mixture of quartz and orthoclase with a little white mica, chlorite, calcite, epidote and magnetite. There is no micropegmatite. The chlorite looks as if it represents biotite. The darker rock which occurs in patches, consists (2536) of chlorite and magnetite set in large interlocking areas of quartz. There are a few crystals of an acid plagioclase and grains of epidote in the rock.

In the bed of the kloof near the edge of the Nieuweveld on Van Rhyn's Plaats, there are some acid patches in the thick dolerite sheet (the one shown in section in Fig. 8). The acid rock forms masses up to nine feet in length, with very irregular outlines; it also forms narrow veins in the surrounding dolerite. Though the outline is so irregular, the two rocks are separated as sharply as possible; there is no visible intermingling. Small patches of dark rock are enclosed by the acid rock. A thin section of the latter (2659) is made of quartz, orthoclase and greenish chloritized mica; the structure is microgranitic. A piece of the dark rock enclosed by the light coloured acid rock is seen to consist largely of chlorite with small crystals of plagioclase in it.

There is a remarkable isolated outcrop of acid rock on the farm Welgevonden. It lies more than a mile from the nearest dolerite and just in front of a low escarpment of sandstone. From a distance it looks like an outlier of this sandstone. The pale-coloured igneous rock forms a kopje about 20 feet high, more or less covered with large boulders with rounded edges; the outcrop is roughly circular and about 100 feet in diameter. The colour is usually pinkish grey, but there are irregularly shaped lumps of finer grained and darker rock in it; it is rather drusy and the cavities are lined with felspar; an occasional felspar crystal about a quarter of an inch long is seen in the rock. The thin section (2649) is seen to be a fine-grained mixture of quartz and albite, with much quartz-orthoclase micropegmatite; there is also pale brownish-green hornblende partly changed to chlorite, and epidote and magnetite. From the appearance of the partly altered

hornblende in this rock it seems likely that some of the chlorite in the other acid rocks of the district represent that mineral.

The dolerite intrusions in this area do not appear to have produced much change in the sedimentary rocks in contact with them. The latter are hardened and often converted into a very fine-grained hornstone for a few inches from the dolerite. In thin sections epidote is occasionally abundant, but the bulk of the rock is too fine-grained to allow the constituents to be recognised. In a section from the contact of the Van Rhyn's Plaats sheet the junction of the two rocks is very sharp. and abundant, but very minute, flakes of greenish mica are the only recognisable alteration products.

## Weathering of the Dolerite.

The surfaces of the dolerite intrusions present different characters according to circumstances. The outcrops of the great inclined sheets are extremely rough ridges, the surface of which is bare rock *in situ* where the slope is too great to allow fragments to accumulate, but the rest is usually formed by a collection of more or less angular blocks with thin, red weathered crusts. These blocks are pitted where the rock has a coarse texture, apparently owing to the augite disintegrating faster than the felspar. Fresh specimens of the rock are easily obtained from these blocks, in which the weathered crust is less than a tenth of an inch thick, but the large flat surfaces met with where the dolerite lies nearly horizontally are much more deeply affected by the weather. Thus, on the top of Bulthouder's Bank, where there is a fairly level surface of dolerite about half a square mile in area, the rock seen *in situ* and not detached in the form of great boulders is deeply weathered, though it is still firm and solid. On such flat surfaces there is vegetation growing along the joints and on the thin soil which covers much of the rock. The ground covered by the great blocks mentioned above is absolutely devoid of vegetation other than lichens attached to parts of the blocks. It is noticeable that the weathered crust under a patch of lichen is distinctly thicker than that of the bare rock.

In many parts of the country behind the escarpment the thick sheets capping high hills of sedimentary rocks have given rise to wide trains of angular blocks from two to six feet long. These blocks are like those forming the crests of the inclined sheet outcrops; they are quite fresh below a very thin red crust, and they ring like metal when struck.

They cover the slopes of the hills to such a depth that no bush can grow in the soil beneath, and occasionally one meets with a block so delicately poised that it moves when touched, though it weighs many hundred pounds. Fatal accidents occasionally happen through careless climbing over this extremely coarse scree, owing to a large block turning over and crushing the unfortunate person. These areas of coarse screes often measure 700 feet in length and half or two-thirds that in width, others again are wider than they are long, and between them dolerite crags project at the top of the hill, and the usual partly debris-covered and slightly terraced steep slopes formed by the sedimentary rocks below. Since the coarse screes often commence at the very top of the hill and there is no ridge or mass of solid rock above their highest level it is difficult to understand their origin. I could get no information from the people who live near them as to whether there were times when the noise made by the blocks shifting is audible, though from the nature of the blocks any movement of a number of them would make a considerable noise. From their manner of occurrence in rather feebly marked kloofs it would appear that they are the result of small landslips. If the shales, etc., below a portion of the thick dolerite sheet were to give way rather suddenly the dolerite might break up along its joints and form such screes, but one would expect in this case to find more blocks of very much larger size than the average amongst them, whereas the largest blocks rarely exceed six feet in length.

These screes of curiously fresh rock fragments often occur near others which are made of rather weathered rounded blocks that do not ring under the hammer, but the two kinds do not seem to be mixed except at their edges. The one kind passes into the other within a distance of 20 feet.

The dolerite which crops out at about the same level as the surrounding ground in valleys or on the great flats north of the escarpment is nearly always deeply weathered, and this is often the case with the same rock on fairly steep flanks of the valleys. Though large boulders of sound dolerite are often found lying on the rotten rock at the foot of steep declivities it is usually difficult to find fresh rock cropping out on the low ground. Dolerite evidently weathers rapdly when covered with soil and vegetation, and the direct influence of insolation and the atmosphere are slight in comparison.

The toughness of the rock towards the strains set up by the alternate heating and cooling during day and night is well shown by the fact that on the crests of the mountains

freshly broken blocks or fragments are extremely rare. When fresh fractures are seen they are invariably splits through large blocks, perhaps eight or ten feet high. A coarse concentric scaling of the rock is occasionally met with in such situations, but not nearly so frequently as in the granite hills of Kenhart and Gordonia. The daily range in temperature of the surface of the exposed blocks on the mountains must be very great; in summer time the favourably exposed surfaces are frequently too hot to keep one's hand on, and at night the temperature must often drop to within a few degrees of freezing point even at that season.

There is a curious contrast between the nature of the surface of the high-lying dolerite sheets and of those at lower levels. Though the surface of the sheets capping Bulthouder's Bank, Groot Tafel Berg, the Tafel Kop on Klaver Vley, Paarde Berg, Gert Adrian's Kop, the Steenkamp's Poort Mountain and other parts which approach or exceed 6,000 feet, are rather rough, they are very much smoother than the surfaces of lower lying sheets such as those of Spitz Kop and Doordrift, Kaffir's Kraal, Albert's Graf, Kruis Van Bloemfontein, and Abram's Kraal, which do not reach an altitude of 5,000 feet. The surface of the latter is exceedingly rough; kopjes, which seem to be made of great rounded blocks piled on one another to a height of 30 feet or so, are scattered all over the sheet; and the intervening space is also covered with large rounded blocks with red soil appearing between them.

The difference between these types of surface must be due to the slightly different circumstances through which they have come. The rock itself is the same. It is probable that the lower lying sheets were subject to the gradual weathering effects of ground water for a long period before they were exposed by circumdenudation, and that the scattered kopjes represent those parts of the rock which suffered least; the deeply weathered portions would be rapidly removed by water as soon as the sheet became fairly exposed, leaving the harder, less weathered knobs of rock projecting. In this way the haphazard distribution of the kopjes is explicable. That low-lying dolerite sheets weather very irregularly is a matter of observation where long road-cuttings have been made, and also where wells have been sunk.

The high-level sheets are much better drained than the low ones, and it may be that they only became bereft of their protective cover of sediments after this efficient drainage was established. In such a case the dolerite on its exposure would present a nearly uniformly sound surface on which

the effects of unequal weathering would only become established slowly.

## Dykes and Pipes of Later Date than the Karroo Dolerites.

On the eastern part of Eende Fontein and Gans Vley, farms on the southern boundary of the Carnarvon Division, there is a well marked "aar" which was traced for three miles. At the north end its course is N. 15° E., but on Gans Vley it turns through south to about S. 5° E. The "aar" is marked by a belt of ground on which the bushes are more abundant and slightly larger than elsewhere, and it can be very clearly seen when looked at from a slight rise, though it would be easy to walk across it without noticing its existence. The ground along the aar is softer than that on either side, and the holes dug by aardvaarks and other burrowing animals are more often seen in this soft strip than elsewhere in the neighbourhood. The width of the aar varies from fifteen to thirty feet in the part seen. The shales along the aar have been tilted up, and at places dip from the aar at 45°; they have been hardened for a foot or less from the contact, and where they are thick bedded rocks the product of alterations is massive very fine grained hornstone.

The ground of the aar is soft and grey in colour, with very slight amounts of certain minerals foreign to the enclosing horizontal shales; the only minerals recognized were small mica flakes and garnets. In walking along the aar some two dozen lumps of hard rock were found, most of them evidently pieces of dolerite of the Karroo type, but four pieces of a serpentinous rock were amongst them. The serpentine rock occurs in more or less rounded masses, which break up easily. It is dull, dark green in colour, with reddish pseudomorphs of serpentine after olivine, and numerous small cleavage faces of mica. The pseudomorphs of serpentine are evidently coloured red by the presence of red iron hydroxide, but the serpentine in the matrix either contains less iron oxide or has it in the form of magnetite. In thin section (2507) the rock is seen to consist of serpentinized grains and crystals representing olivine enclosed in a matrix of biotite, serpentine, perofskite, magnetite or ilmentite and a carbonate, probably calcite or only slightly dolomitic, for the rock gives off bubbles readily with dilute acid. The biotite is very pale in colour; the pleochroism is only just visible, and is abnormal, as in the case of the biotite in some of the melilite-

basalts, lamprophyres and kimberlites of the Cape.[1] It occurs in rather large plates which completely enclose small serpentine pseudomorphs and crystals of perofskite. There is a considerable amount of black iron oxide without definite crystalline shape scattered along the cleavage planes of the biotite, and it looks as if it were the result of alteration of that mineral. The mineral put down as perofskite is in octahedral crystals, more rarely grains, of a yellow-green colour, isotropic when small, but often showing anomalous double refraction in the larger crystals, which measure about .03 mm. in diameter. These crystals and grains are rarely associated with a grain of opaque magnetite or ilmenite, and they are probably original constituents of the rock. Though frequently enclosed by the biotite, they were not seen in the serpentine pseudomorphs. They are just like the perofskite in the lamprophyre inclusions in a pipe on Brak Kuil, Britstown.[2] The Gans Vley rock seems to be very like a mica-peridotite from Crittenden Co., Kentucky, described by J. S. Diller.[3]

The specific gravity of a piece of the dolerite weathered out of the Gans Vley dyke is 2.957, which is a value well within the limits of the figures obtained from the usual dolerites of the Karroo region. Under the microscope (2508) the most abundant constituents are labradorite and augite, the latter forming large grains often partly enclosing the felspar ; this ophitic structure is not so highly developed as in the dolerites from the interior of the thick dykes and sheets. The labradorite has a cloudy appearance along cleavage cracks, and in many cases round the periphery, but the bulk of the mineral is quite fresh. The augite is of a kind usually seen in Karroo dolerites, colourless and without minute inclusions ; it is often partly changed round the periphery owing to the development of small irregularly shaped areas of other substances within the angite ; occasionally the reddish brown colour and pleochroism of one of these areas shows that it consists partly, at any rate, of biotite, but most of them are colourless and have lower refraction and double refraction than the augite. Minute inclusions of biotite are seen in the augite of many Karroo dolerites, but the colourless patches are rarely found in them, and their abundance in the Gans

[1] Ann. Rep. Geol. Com. for 1903, p. 50 ; Ann. Rep. for 1906, pp. 169, 170 and Ann. Rep. for 1908, pp. 119-121.

[2] Ann. Rep. Geol. Com. for 1908, p. 121.

[3] Ann. Journ. Sci. xliv, 1892, p. 286. This paper is not available for reference, but the rock is described on p. 139 of Zirkels "Petrographie," Vol. III, 2nd edition, 1894.

Vley rock is probably due to alteration after the rock was enclosed in the dyke material. The chief peculiarity of the rock is the abundance of small biotite flakes in the interstitial matter between the felspar and augite. The large and small areas of interstitial matter consist of minute prisms of augite, biotite flakes, magnetite, minute grains of a greenish brown highly refracting and doubly refracting substance, which is perhaps sphene, quartz, and colourless material which looks like devitrified glass. Such patches of ground mass are frequently seen in the thinner sheets and dykes of the Karroo, but they do not contain nearly so much biotite as the Gans Vley rock. In parts of the slice minute crystals of green hornblende are found in the ground mass. The unusual characters in this dolerite may be attributed to the action of the dyke rock which enclosed it. Owing to the want of pits along that part of the dyke examined no precise information was obtainable as to the nature of the dyke rock, but it is evidently one that is deeply weathered.

The Gans Vley dyke is said to be traceable for a long distance to the south, but circumstances did not allow me to follow it up, and it was not found along the road between Slang Fontein and Zaai Fontein, which runs from east to west about 16 miles south of Gans Vley.

About 20 miles to the south-east of Gans Vley, on the farm Drooge Fontein, an irregularly shaped fissure or series of pipes filled with lamprophyre accompanies a group of dolerite intrusions which lie along a line directed N. 10° W. Both dolerite and lamprophyre cocur on low ground, which is traversed by a river, and the relative distribution of the rocks is not easily ascertained. Some prospecting pits have been made in the lamprophyre, and the largest pit, which opens a section across part of the lamprophyre, affords a good exposure. Both the east and west ends of the cutting are in lamprophyre, which is much decomposed and crumbles to a loose sand, made largely of mica flakes and particles of carbonates, on being touched. On the east side 30 feet of this rotten rock are exposed, then comes a mass of hard dolerite 12 feet wide, traversed by a vein of lamprophyre 6 inches wide; the western 15 feet of the cutting are in rotten lamprophyre. Several lumps of dolerite and sandstone and shale were seen lying in the decomposed lamprophyre and also in the less decomposed rock.

About 50 yards north of this prospecting cutting there are a few outcrops of a harder rock containing pseudomorphs after olivine and less mica than the decomposed rock in the pits. It is evidently considerably altered by weathering, but

is hard enough to allow a thin section to be cut (2645). Under the microscope the most conspicuous constituents are serpentine pseudomorphs after olivine. The crystals show the usual shapes of olivine, but the serpentine of which they are now made encloses much less magnetite than such pseudomorphs usually have in them, and the magnetite is present in small octahedra scattered about independently of the cleavage cracks, as though it were an original inclusion in the olivine and not a result of alteration of that mineral. The olivine also encloses small flakes of biotite and patches of indefinite material like some of the ground mass of the rock. Every pseudomorph after olivine is coated with a thin, often unbroken, layer of perofskite crystals, octahedral in shape, and of a greenish colour. There are other serpentine pseudomorphs which are free from perofskite at the periphery, and their shapes are not like those just mentioned. These pseudomorphs are surrounded by pale biotite, which is often moulded on them, and the ground mass. The biotite has a pale pinkish red colour; the outer part of large plates is usually more deeply coloured than the interior, and the pleochroism is abnormal, *i.e.*, the absorption is greatest when the short diagonal of the polarizer is perpendicular to the cleavage. It is practically uniaxial. The ground mass consists of minute elongated colourless prisms of augite, which often penetrate the biotite, indeterminate colourless matter, serpentine, calcite, perofskite, and a very little magnetite. No apatite was noticed.

There are several circular patches of soft ground entirely surrounded by dolerite alone or dolerite and hard shale. The largest of these is about 50 yards in diameter. In three of these pits have been dug, and the material exposed is rotten mica-lamprophyre enclosing lumps of dolerite, sandstone, shale, and large masses of amygdaloidal basalt.

The decomposed lamprophyre in one of these pits is trapersed by irregular veins partly filled by calcite, and the calcite is covered with crystals of harmotome.

The amygdaloid is a dark coloured rock with small amygdales of calcite and an undetermined zeolite. In thin section (2646-7) the rock is seen to be very much altered, though in the hand specimens it looks fresh. In ordinary light the outlines of the pseudomorphs after felspars are visible, and they are arranged as in basalts, but there is nothing to indicate the way in which ferromagnesian minerals occurred. The rock thus forms a strong contrast to the fresh amygdoloidal basalts in the Frank Smith mine, and the pipes at Uintjes

Berg (Carnarvon)[1] and Riet Gat (Victoria West)[2]. There seems to have been a fair amount of groundmass between the felspars, but its former nature is uncertain, grains of ilmenite or magnetite are the only possibly original minerals. Between crossed nicols the whole rock is seen to be made of alteration products, which have crystallized independently of the distribution of the original constituents. An epidote mineral, a zeolite, calcite and probably chalcedonic silica were recognised.

To the east of one of the lamprophyre patches appearing through dolerite there is a more or less circular patch of what was taken to be brecciated shale or sandstone, separated from the dolerite by a few yards of unbroken sedimentary rock. In hand specimens the rock is seen to be made of flat fragments of a pale coloured, close-grained rock, usually less than an inch long and less than a quarter of an inch thick, separated by a greenish cementing substance which breaks away on the weathered surface and leaves tabular spaces owing to the roughly parallel arrangement of the fragments. No section was cut from one of those fragments on account of the difficulty of obtaining a suitable piece, but a section cut from a compact looking piece between the fragments (2651) shows no trace of sedimentary material. The section is made of orthoclase felspar in crystals half a millimetre long or less, elongated in the direction of the clino-diagonal axis. These crystals are crowded with very thin needles of some mineral, apparently green in colour, which are too small for identification, though they may be a pyroxene of the kind seen in the matrix, for a few larger needles of that mineral are also enclosed by the orthoclase crystals. The crystals occasionally show distinct signs of twinning, though of a kind difficult to determine; between nicols lenticles of material orientated differently from the enclosing substance can be seen in a crystal which appears uniform in parallel light. These laminae are present in small amount only, and the bulk of the crystal has approximately straight extinction, though owing to the ill-defined characters of the edges which are always encroached upon by pyroxene needles, the observation cannot be made with accuracy. No twinning of the microcline type was noticed. The matr i in which these crystals lie is a holocrystalline granular mixture of felspar and probably quartz, with innumerable needles of the pyroxene and amphibole described below, and small patches of a yellowish chloritic substance. The presence of

[1] Ann. Rep. Geol. Com. for 1906, p. 146.
[2] Ann. Rep. Geol. Com. for 1909, pp. 102-103.

quartz is surmised from the clear character of small patches of the ground mass, for the felspar is slightly turbid. Quartz can only be present in very small quantity. The green needles are slightly pleochroic with extinction angles up to 45°, and in transverse sections they show the forms of pyroxene prisms. They probably belong to the aegerine-augite series, and resemble closely the paler part of the crystals composed of augite and aegerine in the lamprophyre of Riverside in Prieska[1] and other rocks of that type in the north of the Province. Typical aegerine was not found. The amphibole is less abundant than the pyroxene, and it forms smaller needles. It is deep brown in colour and slightly pleochroic in tones of greenish-brown and brown. The interference colours are low, and the extinction angle ranges up to about up to about 20°. Transverse sections show the characteristic amphibole form. The mineral is very like an amphibole in a lamprophyre from Hanover, Barkly West. It is more like arvedsonite than any other well-known mineral. These needles of pyroxene and amphibole accur throughout the matrix, and the pyroxene is abundant in the felspar phenocrysts, but they are most closely packed round those phenocrysts, often in radiating bunches.

The green material round the pale fragments in the hand specimen, when powdered and placed under the microscope, is seen to consist of the green pyroxene described above, and the powdered substance of the fragments also shows this mineral and much undetermined substance. The absence of recognizable quartz grains from the powder of the fragments makes it doubtful whether they are of sedimentary origin, and their true character remains to be determined. The peculiar character of the matrix of the breccia was not recognised in the field, and the occurrence requires further investigation.

No rock quite like this has been previously met with at the Cape, and it undoubtedly has some resemblance to the grorudites described by Brögger from the Christiania region.

On the farms Gans Fontein in Beaufort West there is a rather well defined elongated pipe filled with a kimberlite. It is about 80 yards long and 33 wide, but its shape (Fig. 9) is irregular. Two large masses of sandstone crop out at the surface of the pipe. The surrounding hard shale and thin sandstones are not turned up at the edges, and no dyke is connected with the pipe at the surface. The position of the pipe is marked by a slight rise of pale, almost white, soft

---

[1] Ann. Rep. Geol. Com. for 1908, p. 120.

ground, with a clump of bush on it, amongst ground covered with outcrops and fragments of shale and sandstone. The kimberlite itself does not crop out, but fragments of dolerite, sandstone and shale, and basic granulites, as well as small pieces of the minerals derived from the latter, are abundant in the soft soil. Two prospecting pits have been dug in the soft ground; they are now almost completely filled in by the collapse of the sides, but I was told by the owner of the farm that the deeper of the two was 27 feet deep when abandoned. A heap of the fairly fresh rock remains round the deeper pit.

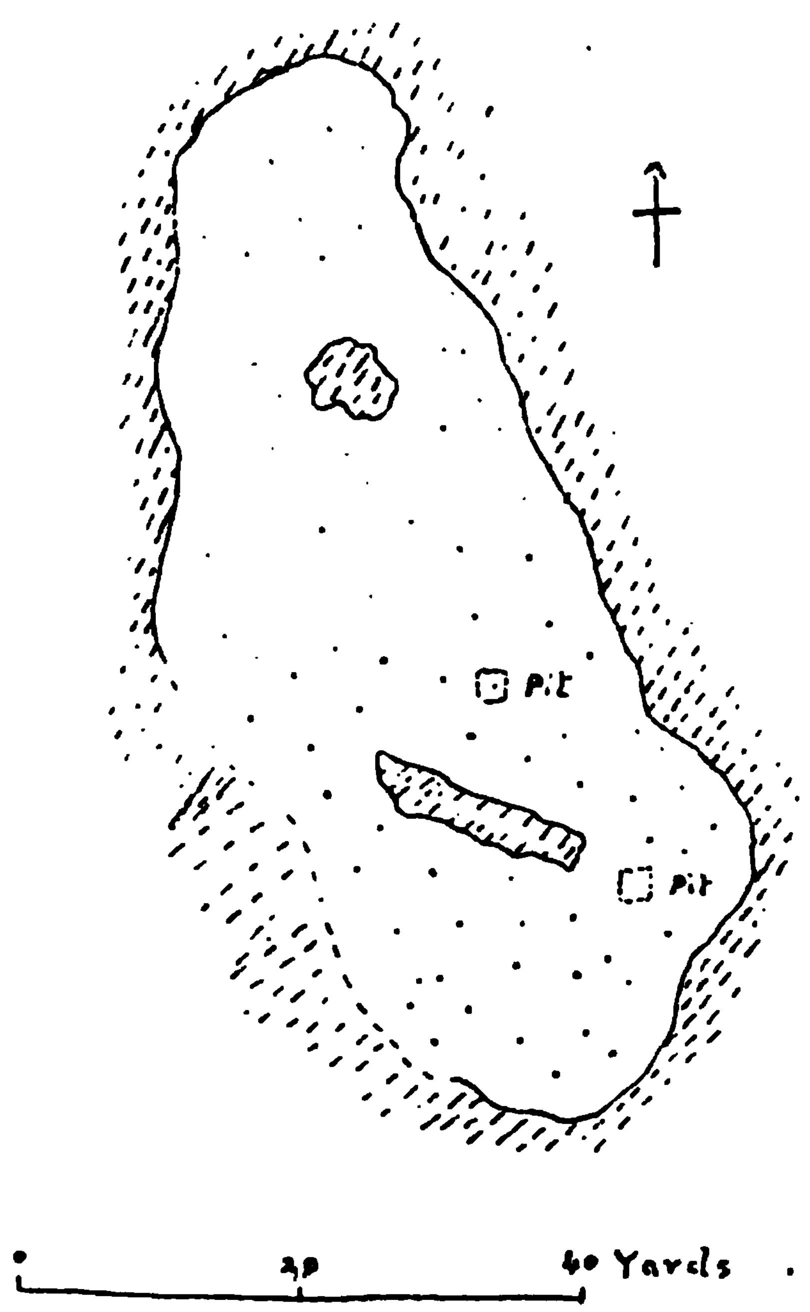



FIG. 9.—Plan of pipe on Gans Fontein, Beaufort West, showing two blccks of sedimentary rcck in the weathered Kimberlite.

It is a "hardibank," a greenish blue serpentinous rock containing recognizable fragments of olivine, ilmenite, biotite, diopside, and the rocks mentioned above. The ilmenite forms lumps as much as two inches long, but the other minerals occur in smaller pieces only. The rock fragments may be of any size up to that of the large mass of sandstone, about 15 yards long, shown in the plan. The basic granulites rarely form lumps more than six inches in diameter. All the fragments seen, except the ilmenite, have a zone of altered material round them derived from themselves. The

olivine and biotite have suffered most change. In shape the fragments are often rounded, the granulites always so, but the pieces of sandstone and shale are usually angular. There are occasional amygdale-like masses of calcite surrounded by thin layers of chlorite. In thin section (2635-6-7) there are seen large numbers of serpentine pseudomorphs after olivine up to nearly a millimetre in length; these show the outlines of olivine crystals. The larger olivines seem to be irregularly bounded in the hand specimens, and they are less altered than the small ones. The groundmass is made of alteration products, minute grains of iron ores and crystals of perofskite. Calcite and serpentine is abundant, and there is much fibrous material with varying double refraction which may be antigorite.

A rather coarse grained granulitic rock forming a rounded and rather flattened inclusion in the hardibank is seen in thin section (2641) to be made of olivine, enstatite and a little magnetite partly altered to haematite. The olivine is quite fresh, but the enstatite is altered to a small extent along a few cleavage cracks. Neither mineral has idiomorphic outlines. This rock is a saxonite, and is similar to rocks of that type found as inclusions in the pipes of Griqualand West and described by Mr. du Toit.[1]

A rock containing much green diopside was found as a boulder with rounded shape and a smooth surface. Biotite is scattered through it, and red garnet is seen at one part of the periphery, but not in the interior. In thin section (2642) the constituents are seen to be diopside, olivine partly changed to serpentine, and very strongly pleochroic biotite. The olivine shows crystal forms in one case, but the minerals generally are without them.

Another olivine-enstatite rock (2638) occurs in a rounded boulder enclosed in the hardibank. There is a slight amount of carbonates and serpentinous matter between some of the irregularly shaped grains, and a few small flakes of a pale biotite, one of which shows well defined hexagonal boundaries, lie in this mixture.

Another rounded lump contains a large amount of biotite and ilmenite. In thin section (2640) it is seen to be made chiefly of enstatite, biotite and ilmenite, but an irregularly shaped grain of olivine is also seen in the slice. The enstatite is in irregularly shaped pieces surrounded by biotite or ilmenite, but it often encloses biotite. The larger enstatites are broken up and the fragments slightly displaced and,

---

[1] See Ann. Rep. for 1906, pp. 161-3.

separated in places by a mosaic of enstatite and biotite. The enstatites often show strain-shadows between crossed nicols. The biotite, a pale variety, always shows the effects of strain and frequently has been broken up. The enstatite has given rise to a small amount of serpentinous material, but small veins of the latter seen in the slice may have been introduced from the enclosing rock.

A slice (2639) was cut from one of the lumps of dolerite found in this pipe. The rock is of the usual type of rather coarse ophitic dolerite without olivine found in dykes and sheets in the Karroo. The constituents are labradorite, augite, iron ores and a very little red biotite. The felspar appears to be quite unaffected, but the biotite is distinctly bleached and cloudy, and part of the augite has been changed into a brownish-white substance, which is almost opaque, in thin section. This is a kind of change not seen in the specimens of Karroo dolerite taken from outcrops of that rock.

An opportunity occurred of again examining the pipe on Balmoral (Ratel Fontein) in Fraserburg, which was described by Prof. Schwarz and the writer in the Report for 1900, p. 60. Though some further prospecting has been done on this pipe there is little further information to be had. Measurements showed that the pipe is elongated from east to west at the surface, the diameter in that direction being 110 yards, while the shorter diameter is only 90 yards. On the north side of the pipe there is a short dyke with N. 40° E. course, which does not join the pipe at the present surface. This dyke is filled with a soft greenish decomposed rock containing many pseudomorphs, apparently after olivine, but no ilnenite, mica, or garnet was seen. In the pipe itself a prospecting pit shows the presence of a greenish muddy material containing small flakes of mica, and small rounded lumps of ilmenite and garnet, but it is quite incoherent. Considering the amount of prospecting done in this pipe it is remarkable that not a single piece of the basic granulitic rocks was noticed on either of the two visits. Dolerite, sandstone and shale are the only rocks seen in the soft matrix.

On the farm Koe Kraal, in Fraserburg, several prospecting pits have been opened in an oval patch of soft ground lying just to the north of the northward dipping sheet of dolerite on the south of the farm. The holes are shallow and no fresh rock was obtained in them. The rock thrown out is a bluish earthy material containing a sprinkling of pale brown mica

flakes up to a tenth of an inch in diameter. Granulite, garnet, ilmenite and diopside were not seen in this earthy material, but it encloses numerous small lumps of dolerite and shale. It evidently fills a pipe, which measures approximately 140 yards in a N. 40° W. direction and 70 yards across.

On the south-western side of the farm Eende Kuil, in Sutherland, there is a pipe filled with various materials foreign to the surface rocks of the neighbourhood. The pipe lies within 300 yards of the farm boundary. The limits of the pipe are not clearly defined, but from the position of sandstone outcrops the maximum diameter cannot be more than 800 feet, and the shape may be rounded or irregular, though it cannot be in the form of a dyke. No dyke was seen in connection with this pipe, and at the surface at least it is independent of the lamprophyre dyke seen about three miles to the east-south-east. The sandstones were not found to be turned upwards in the outcrops nearest the pipe rock.

Three prospecting pits have been dug in the pipe ground. The material throws from the easternmost hole is a soft earthy stuff without many visible mica flakes. Boulders of shale, sandstone, dolerite and the peculiar glassy-looking quartz rock described below are abundant. Joints in the blocks of sedimentary rock are filled with pyrites, and small lumps of that mineral are scattered through the earthy material here forming the main contents of the pipe. The western part of the pipe is chiefly filled with a rock rich in mica, resembling in character the lamprophyre from the dyke on the south-eastern portion of the farm and described in detail below. This lamprophyre contains very many fragments of shales and sandstones from the Karroo beds, dolerite, basic granulites and peculiar quartz rocks. The shales and sandstones are considerably altered, the former to bluish hornstones and the latter to quartzite. Small pieces of red garnet and green diopside are seen in the lamprophyre, they are derived from the basic granulites. The lamprophyre from this pipe did not afford a specimen which seemed hard enough to be worth cutting. Both the rotten lamprophyre and the soil over it contain much gypsum. In addition to the richly micaceous lamprophyre in the western part of the pipe there is a less micaceous variety there with much serpentenized olivine in it. The relation of the two varieties could not be ascertained.

The granulite found in lumps in the rotten lamprophyre is a rather coarse grained rock made of green diopside, red garnet, brown mica, plagioclase, green hornblende and sphene.

Under the microscope (2523) diopside is seen to be the most abundant mineral; it is bluish-green in colour in the section and is not pleochroic. It contains many rather large needle-like inclusions of a greenish mineral arranged in three directions. Garnet is the next most abundant constituent; it is pink in the section and has very minute doubly refracting needles in it arranged in three groups, apparently parallel to the edges of a cube. A basic plagioclase is fairly abundant, and brown biotite brown hornblende and sphene are present in small quantity. The minerals are usually fresh, but there is often a narrow zone of rather opaque substance around the garnet.

The peculiar glassy-looking rocks mentioned above are abundant in this pipe; very similar rocks were obtained by Mr. du Toit at Wrigley's Kopje and Secretaris in Griqualand West, from blue-ground pipes. The constituents are quartz in a rather peculiar form, carbonates, chiefly calcite, dull black inclusions of iron ores and a small quantity of a micaceous substance. The proportion of quartz and calcite varies; the rocks have a grey colour generally, with green and yellow stains in patches. In thin section (2518-2522) the quartz, which was determined by physical and chemical tests in the hand specimens, shows undulatory extinction, and evidently replaces other minerals. The calcite is also the result of secondary change. It is not clear what these rocks were originally, but in some instances the arrangement of the inclusions of iron ores within the quartz suggests that serpentine pseudomorphs after olivine have been replaced by quartz. It shows some resemblance to the silicified portion of a lamprophyre from the dyke to be described now.

On the south-eastern part of Eende Kuil an aar which crosses the Great Riet River in a W. 16° S. direction has been prospected on at intervals along 1,500 yards of its length. The aar is marked by a line of bush, and at places by the upturned edges of the shales along it. The prospecting holes show that the width of the dyke which gives rise to the aar varies from two to five feet. The material exposed by the prospecting holes is a loose earth near the surface, but at a depth of four feet or so flakes of mica become abundant; still further down a fairly hard lamprophyre containing lumps of sedimentary rocks and granulites, and numerous fragments of minerals derived from the latter, is exposed.

The section represented by the accompanying sketch is laid bare at the western end of the largest prospecting pit, and it is typical of what is seen in the others, except that the long strip of hard rock seen here disappears in the fourth

hole to the west, at a distance of some 400 yards from the large pit. The bending upwards of the rocks at the sides of the dyke diminishes appreciably in the 12 feet exposed in the pit, and it is probable that it disappears altogether lower down. The sedimentary beds exposed in the pit have uniform characters and are rather broken at the contact, so that it is difficult to decide whether there has been any shifting of the sides of the dyke at this spot. In another pit the presence of a thin layer of hard sandstone on ether side shows that there has been a downthrow of 18 inches on the south. The vertical strip of hard rock shown in the sketch extends for some 300 yards in the dyke, according to exposures in three other pits. It appears to be due to the impregnation of the lamprophyre by silica along a well-defined plane.

The lamprophyre is a grey rock with very numerous pieces of biotite, often nearly an inch in diameter and a tenth of an inch thick. The edges of the crystals are rounded, so that the rock appears to be full of water-worn flat pebbles. They are arranged more or less parallel to the walls of the dyke. In thin section (2529) the rock is seen to be considerably altered. The biotite is very abundant, both in large rounded plates and small crystals, which often show idiomorphic outlines. It is not very strongly pleochroic, yellowish to red-brown, and the pleochroism is of the normal kind throughout the greater part of each flake, but the periphery in large plates often shows the abnormal pleochroism noticed in many of the lamprophyres and melilite-basalts of the Cape; the small crystals rarely have this peculiarity. Small grains and prisms of a colourless augite are scattered through the groundmass, which also contains magnetite. The groundmass is largely made of calcite, quartz and dusty looking material. The presence of quartz in such a rock is unusual, and might be suspected to be of secondary origin, but though some quartz which shows undulatory extinction and forms a minute mosaic is very probably of that nature, the appearance of other portions forming clear areas wrapping round the mica, augite and iron ore, is that of an original constituent. In places the mica is altered to a green chlorite. A section (2528) from a hard band running through the lamprophyre, shown in the sketch in Fig. 10, shows the replacement of the rock by calcite and quartz. In places the original mica, augite, iron ores, and also apatite, can be seen, but most of the rock is calcite and chalcedonic silica, though parts show the large quartz areas with undulatory extinction that make up most of the peculiar boulders in the pipe to the west. If the chalcedonic silica here were to be converted

into the peculiar quartz described above from the boulders, there would be a very close resemblance between the altered part of this lamprophyre and the rock of the boulders.

Several fair sized lumps of granulitic rock were found in the lamprophyre, but they all belong to one and the same type of rock and are richer in felspar than the inclusions of granulitic rocks in these dykes and pipes usually are. Four slices (2524-2527) were cut from the granulites from this dyke. The constituents are the same in each case, viz., labradorite, very pale greenish diopside, very pale garnet, brown biotite in small quantity, dark brown sphene and a little calcite and some nearly opaque mineral forming a rim round the

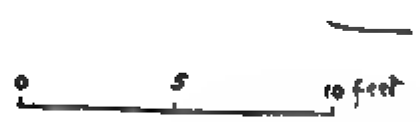



Fig. 10.—Section exposed at Western end of a prospecting hole on Eende Kuil.

garnet in two of the slices. Very thin needles of a green mineral are enclosed in the garnet and diopside ; it is probably a green monoclinic pyroxene, for the extinction angle is as high as 30° (measured on needles in garnet), the double refraction is high, and in a few cases transverse sections can be seen to have the pyroxene shape. These needles and the garnet are the only minerals which have idiomorphic form, but the garnet only occasionally shows it.

About three miles south of the dyke just described there is another aar crossing the Great Riet River on Elandsberg in a W. 12° S. direction. It was seen at intervals over four miles of country, and it crosses an inclined sheet of dolerite east of the river. In general appearance it is like the Eende Kuil aar ; the shales along it are turned upwards, and a few small lumps of dolerite were found on its surface, but no granulite, mica, or garnet was seen. There are no prospecting holes or wells along it, but it is probably one of the lamprophyre dykes.

On the southern part of Matjes Fontein[1] in Sutherland, and on the neighbouring part of Rogge Kloof, there is an aar with a W. 40° S. course. It was traced to within about five miles of Saltpetre Kop. No good outcrops were met with in the aar, but at one or two spots the dyke rock just reaches the surface of the ground. In hand specimens the rock is greyish blue and resembles a " hardibank " in appearance. The greyish-blue matrix contains numerous small pieces of shale, ilmenite, mica, augite, hornblende and olivine or serpentine pseudomorphs after olivine. The weathered surface is brown, and looks like the surface of an impure limestone. In thin section (2515-6-7) the matrix is seen to consist of green serpentinous matter, much calcite, small crystals of melilite and perofskite. The perofskite contains many minute black inclusions. The melilite occasionally forms good hexagonal crystals on which the mineral character can be seen. The larger crystals have a zonal structure, the interior being made of material with lower double refraction than the exterior. The double refraction is positive. In the thin sections no olivine is seen; the mineral is replaced by serpentine and carbonates. The hornblende is a very pale brown variety, and its pleochroism is weak. The extinction angle ranges up to 20°; some of it encloses rutile needles. The augite is colourless, and occurs, like the hornblende, olivine, ilmenite and biotite, in rounded lumps. The biotite has normal pleochroism, and is surrounded by a border of black dusty material.

A very interesting rock was found on Tonteldoos Fontein by Mr. A. R. Walker while collecting fossil bones there. Tonteldoos Fontein is the adjoining farm south of Rogge Kloof. Mr. Walker had only time to secure a piece of the rock, which forms a small kopje, but could not decide whether it actually fills a pipe. It is a well preserved rock with a few crystals of olivine over a quarter of an inch long. In thin section (2546) there are seen to be very numerous small crystals of olivine, which are partly altered to serpentine; these lie in a matrix of very small purplish-brown elongated crytals of augite, strongly pleochroic reddish biotite with normal pleochroism, magnetite, a little perofskite which does not form good crystals, a little apatite and calcite, and a clear colourless material with low refractive index and very

1. This is the neighbourhood in which occur a large number of pipes and dykes filled with various materials, ranging from melilite basalts to breccia containing little material derived directly from igneous rocks. See Annual Report Geological Commission for 1903 and Trans. S.A. Phil. Society, xv., pp. 61-83, 1904.

low double refraction. This mineral occurs as if it were an original constituent of the rock ; it encloses the small crystals of augite and other minerals just as a glass would. It has a cleavage occasionally, and extinction takes place parallel to it. There are many areas of the mineral which are almost if not quite isotropic, but they are too small to afford any evidence with convergent light. The mineral alters to a very finely crystalline pale green aggregate. It has not been tested chemically. This rock has a resemblance to the dykes from Van Rhyn's Dorp described on page 32 of the Report for 1904, and referred to as a camptonite by Mr. A. L. du Toit on p. xliii. of the Proceedings of the Geological Society of South Africa, vol. xiii.

## SUPERFICIAL DEPOSITS.

The soil in this district is generally thin. Away from the immediate vicinity of the rivers the ground is stony, and rather thin soil lies between the stones. The proportion of stones to soil decreases the further north one goes from the escarpment, and in the same direction the frequency of very large areas directly underlain by shale becomes greater. These shale areas are naturally more uniformly covered with soil than the sandstone terraces and hill-tops.

The fragments lying on the surface are of quite local origin ; no gravel terraces were met with on the Nieuweveld.

Alluvium is found along the rivers above the points where they enter thick dolerites. The Zak River has large alluvial areas at such places, and the smaller streams have correspondingly smaller patches. These alluvial tracts are, in places, cultivated under irrigation, either by water pumped from kolks or led from small dams, but agriculture is not carried on to any great extent as yet. The fertility of the alluvial areas seems to be equal to that of the similar ground in the Great Karroo, judging from the appearance of the grain crops and lucerne. It is probable that a partial remedy against the disastrous effects of the severe droughts to which the country north of the great escarpment is subject will be found in making full use of the opportunities for growing food for the small stock on the irrigable alluvium.

Behind the dolerite sheets the alluvium often reaches a thickness of 20 feet, as can be seen in the numerous dongas which have been allowed to develope there. Gravelly beds are usually only seen at the base of such sections, in which is seen layer upon layer of fine silt, often more or less cemented by carbonate of lime. In the alluvium of the Zak River and of its larger tributaries there are shells of a large

bivalve mollusc, *Mutela* or *Unio*, which is probably still living in the Zak River, and the smaller shells of *Planorbis* and *Physa*.

Where the river runs in a narrow valley, or close under a steep side of its valley, pebbly beds alternate with the silt.

An interesting section through a tract of alluvium in a narrow valley has been exposed by the river on Klip Heuvel, south of Fraserburg. The depth of the section is 15 feet ; at the bottom of it is hardened shale, on which lie dolerite boulders mixed with sandstone and hard shale pebbles in a red gritty matrix ; above this layer, evidently an old bed of the river, lie no less than 12 old soils between fine silt and pebble beds. The old soils are marked by thin black layers containing much vegetable matter. The pebbles are sub-angular or angular in shape, some well rounded. The river must have filled up this part of its valley after excavating it to its present depth, probably owing to the grade becoming very low for some distance along this part of its course, as it cuts down below the thick sheet which now forms the steep sides of the valley rising above the section just described: the downward cutting of the bed in this stretch was probably checked by the northern limit of the sheet, which is steeply inclined, so that there is a permanent dolerite sill some distance down stream. The late activity of the river seems to have been caused by the destruction of vegetation in the vley behind this sill since the occupation of the country.

### *Surface limestones.*

Turfaceous deposits which are so widespread in the country near the Orange River are scarce in this region. In the Nieuweveld only small patches round springs were seen. Though the alluvium of the rivers occasionally contains enough lime to give it a firm consistency, the proportion of mechanically deposited silt is so large that the material is very different from the surface limestones of the north.

In the dolerite areas thin coats of white calc-tufa are oftent seen on joint faces and in small patches between the boulders.

Nodules of hard limestone, such as are often seen in the soil in the Tanqua Karroo and in many parts of the south of the Colony were not noticed in the country north of the escarpment, though they are frequent in the Gouph at its foot.

A very remarkable deposit of surface-limestone covers a wide area to the north-east and east of the town of Beaufort West, between the dolerite escarpment of Elands Fontein Sunnyside and other farms to the east and the undulating

plain of the Gouph to the south. The limestone forms a plateau sloping gradually to the Gouph. Only a small part of it was traversed last year, and there are many circumstances in connection with it remain to be investigated.

In the area traversed the southern limit of the limestone lies south of the eastern part of the Beaufort dykes. The limestone is being cut into by streams, and towards the dolerite escarpment it apparently passes into red soil, though whether this is due to the red soil covering the limestone or to a change in the character of the rock itself is uncertain.

The limestone contains subangular boulders of hard shale, sandstone and dolerite, though the last named rock is not very abundant in the limestone along the road to Sunnyside from Beaufort West. The boulders lie on the surface of the ground in considerable numbers in places.

The general appearance of the limestone plateau is very like that of the boulder covered ground on the Dwyka tillite area in Prieska, though the variety of rocks found as boulders in the north is not met with here. The occurrence probably explains the insertion of an area of "glacial conglomerate" near Beaufort West in some early geological maps of Cape Colony.[1]

## WATER.

Underground water is made use of to a very large extent in Fraserburg and the north of Beaufort West. Springs are not abundant; but in many cases they have been opened up and the supply increased by pumping, so that the original spring is not seen.

Most of the water is obtained from wells, which are not very deep, rarely over 50 feet. The wells are usually sunk near a dolerite dyke or even on one.

Behind the great inclined sheets water very often oozes out of the shales, and many wells are sunk in such positions. It often happens that the water is obtained from wells below the dolerite outcrops, and small springs are also found there, though from the lie of the country it would be expected on the other side of the dolerite if the latter always held back underground water. If such cases are due to a leakage through the dyke or inclined sheet one would expect to find that water is at least as near the surface behind the sheet as it is on the front of it.

Water is occasionally seen oozing out at the base of a thick sheet of dolerite, just at its junction with sedimentary rocks, but no large supply was seen at such a place. The water

[1] E. J. Dunn, Geological Map of Cape Colony, 1st Edition, London, 1873.

at Putter's Vley, on the northern margin of the Bulthouder's Bank outlier, is found at the junction of the two rocks about 480 feet below the top of the hill. On the farm Paarde Kraal, to the north-west there is an interesting occurrence of water at the junction of the overlying sheet with a shale inlier at much less than 300 feet below the top of the escarpment behind. The water in these cases must come from the dolerite area.

# GEOLOGICAL SURVEY

OF

# MACLEAR AND PORTIONS OF ENGCOBO, MOUNT FLETCHER, QUMBU AND MOUNT FRERE,

BY

ALEX. L. DU TOIT.

# GEOLOGICAL SURVEY

OF

# MACLEAR AND PORTIONS OF ENGCOBO, MOUNT FLETCHER, QUMBU AND MOUNT FRERE.

BY ALEX. L. DU TOIT.

The area surveyed forms an extension in a southerly and easterly direction of the Districts of Elliot and Barkly East, which were examined in 1903 and 1904 respectively.[1] On the north-west the boundary is the rest of the Drakensberg, which forms the defining line between Barkly East and the Transkei, while to the north-east the work was carried as far as the town of Mount Fletcher. The southern and eastern limits are, however, very irregular, for, owing to the extremely rugged nature of the country coupled with the scarcity of roads, it was found impossible to work continuously in any desired direction. In addition a certain amount of work was carried out in Mount Ayliff, the results of which form a second Report, and, in travelling from Katkop to Mount Ayliff and back, a strip of country of variable width lying mostly to the west of the main road was mapped between Qumbu and Mount Frere.

In Maclear the Divisional Map on the scale of 400 Cape roods (or about 1 mile) to the inch formed the basis of the work, and only required corrections to the topography and alterations in roads ,etc., to render it serviceable. In Mount Fletcher also a small block of country has been cut up into farms and a map of these was available. But the remainder of the country investigated remains unsurveyed, and for the work a map had to be constructed in the field.

Fortunately the Secondary Triangulation has just lately been carried out over this section of the Transkei, and by working from these beacons, which are spaced from 8 to 12 miles apart, a plane-table survey could be carried out on the scale of 800 Cape roods (or about 2 miles) to the inch. The new map of the Transkei on the same scale, which is in course of completion by the Surveyor-General's Department, was found of great service for general purposes, though not accurate enough for geological work.

[1]Annual Reports Geol. Com. for 1903 and 1904.

*Geological Formations.*—The country is composed of the sediments and volcanic rocks belonging to the uppermost half of the Karroo system, as shown below in descending order. From the crest of the Drakensberg the surface descends in a series of steps, and, consequently, owing to the nearly horizontal character of the beds the older strata occupy the low ground, and the younger build up the mountainous portion.

| | | |
|---|---|---|
| Stormberg series | Drakensberg or Volcanic beds (up to over 3,000 feet) | Basaltic lavas with occasional thin beds of sandstone and in places underlain by volcanic ash. |
| | Cave sandstone (50-800 feet) | Cream coloured to pink fine grained felspathic sandstone, feebly bedded. |
| | Red beds (1,200 feet) | Purple, red, and blue shales, with yellow sandstones. |
| | Molteno beds (1,800 feet) | Coarse pebbly, and finer felspathic sandstones with blue and grey shales and mudstones, with coal seams and fossil plants. |
| Beaufort series | Upper Beaufort or Burghersdorp beds (over 2,000 feet) | Yellow sandstones, with purple, red and blue shales, mudstones, and flaggy sandstones. |

Numerous sheets and dykes of dolerite penetrate all these beds, though they diminish in numbers towards the top, so that such intrusions are rare in the volcanic beds.

The strata are lying at very low angles, usually from 1° to 3°, the general dip being from south-east or east to north-west or west; but in a number of localities there are steeper dips, and sometimes the strata are disturbed by small flexures of a monoclinal nature. One of these, for example, crosses the main road to Mount Fletcher, at Moordenaar's Nek, and strikes in a north-westerly direction over the Luzi River towards the triangulation beacon Fletcherville. The dip is towards the south-west at from 4° to 15°. Another flexure, 10 miles in length, runs from the farm Kingsford, in Maclear, westwards through Tent Kop and dies out below the Drakensberg, the dips having in places a value of over 20°. Beneath the Drakensberg the strata frequently possess irregularities in dip and this is especially the case in the south-west around the Gatberg, details of which will be given later.

*Topography*.—The outstanding feature in the area is the great escarpment of the Drakensberg, which rises from four to five thousand feet above the low ground at its foot.

In Elliot the direction of the escarpment is east and west, but where the latter enters Maclear it makes an abrupt bend and now runs in a remarkably straight line a little east of north to just beyond Ongeluk's Nek, after which it strikes east-north-east to the Natal boundary.

The Secondary Triangulation which has been completed over this section of the Drakensberg has furnished the altitudes of a number of points along the escarpment, proving that throughout a distance of about 170 miles the general height of the crest exceeds 8,000 feet above sea-level, and that this figure is much exceeded in the middle portion of the section. The following altitudes[1] are given here of points taken in order from south-west to north-east :—

| | |
|---|---|
| Waschbank Peak[2] .. .. | 8,428 feet above sea level. |
| Mount Enterprise .. .. | 8,410 ,, ,, ,, |
| Bendearg[2] .. .. .. | 9,079 ,, ,, ,, |
| Pondo Gates .. .. | 8,360 ,, ,, ,, |
| Mount Blyth .. .. | 8,435 ,, ,, ,, |
| Scobell's Kop .. .. | 8,953 ,, ,, ,, |
| Lehana's Pass .. .. | 9,258 ,, ,, ,, |
| Thatsana .. .. .. | 9,675 ,, ,, ,, |
| Ongeluk's Nek .. .. | 9,508 ,, ,, ,, |
| Draken's Rock .. .. | 8,941 ,, ,, ,, |
| The Twins .. .. .. | 8,818 ,, ,, ,, |
| Makomering .. .. | 8,483 ,, ,, ,, |
| Nquatsha's Nek .. .. | 7,115 ,, ,, ,, |
| Montai .. .. .. | 8,157 ,, ,, ,, |
| Mount Fred .. .. | 8,257 ,, ,, ,, |
| Hlangweni North .. .. | 7,869 ,, ,, ,, |
| Thule .. .. .. | 8,323 ,, ,, ,, |
| Watershed .. .. .. | 8,184 ,, ,, ,, |

The cliff along the escarpment in Maclear and Mount Fletcher is formed by basaltic lavas and rises above a series of spurs which extend out from the Drakensberg for no small distance, as much as fifteen miles in places, and which separate the headwaters of one river from those of another. These spurs are composed principally of Cave sandstone and Red beds, though in the northern part of Maclear the lowest part of the Volcanic beds forms a wide plateau at an altitude of from 6,000 to 6,500 feet above sea-level.

1. Annual Reports of the Surveyor-General for 1909 and 1910.
2. Geodetic Survey of South Africa, vol. v. Report on Transvaal and Orange Free State. London.

Owing to the slight dip of the beds towards the nórth-west the ends of the spurs are frequently higher in level than their roots, where they unite with the main mass, so that we find points reaching a considerable height away from the Drakensberg, namely Castle Rocks, 7,029 feet and Paarde Berg, 7,024 feet in Mount Fletcher, and Adams, 6,520 feet on the great outlying mass of the Prentjes Berg near Ugie.

The Molteno beds form characteristically terraced country over the eastern parts of Maclear and Mount Fletcher, while, owing to the slight departure of the strata from horizontality, high ground is again found extending just east of the Maclear border, with many points rising to from 5,000 to over 6,000 feet above sea-level.

Towards the south-west sheets of dolerite cap much of this high ground; further north, however, nearly all the ridges are composed of the coarse pebbly sandstones typical of the Molteno beds, for example, View Hill, 5,137 feet, N'Tabodule, 5,824 feet, and Lady Kok or Trinity Peak, 6,613 feet.

From this belt of high ground the surface falls abruptly, and there is a great escarpment from 2,000 to nearly 3,000 feet in height, which goes by the somewhat inappropriate name of the Zuurberg, though it is really the irregularly eroded scarp of a denuded plateau. It is the extension of the belt of high ground on the southern border of Xalanga, and its regularity is destroyed by the great gorges which have been cut through it by the rivers which take their rise below the Drakensberg, the Xuka, Bashee, Inxu, Tsitsa, Tina and Kenigha, taking them in order from south to north.

Owing to the erosion performed by the Xuka and Bashee and their tributaries the scarp has been worn into four narrow spurs separated by broad precipitously sided gorges at the extremities, on three of which stand the trigonometrical stations, Gulindoda, Gaka and Bazeia. The plateau then makes a sweep to the north-east to a point overlooking Tsolo, but is brought back to the Maclear border by the gorge of the Tsitsa River; this portion falling within Tsolo and Umtata has not yet been examined geologically. Between the Tsitsa and Tina Rivers the plateau sends out another lobe, and at N'Tabodule there is almost the only point where the escarpment does not end in a precipice, advantage of which has been taken in making the main road from Katkop to Qumbu.

Between the Tina and Kenigha Rivers the plateau juts out in an extremely long narrow spur, which terminates in the Umgano Range 45 miles from the Drakensberg, overlooking Mount Frere; points along it exceed 6,000 feet above sea level.

The territory at the foot of this great escarpment has a general altitude of from 3,500 to 4,500 feet above sea-level, undulating or hilly along the divides, and cut into ravines along the main rivers. The depth of soil is commonly greater than on the plateau, and the rocks are, therefore, not so well exposed. In the kloofs and under the escarpment there are numerous patches of forest which are fortunately being protected by strict legislation.

*Hydrography*.—With the exception of the Bashee, which takes its rise in the indentations of the Zuurberg, the rivers originate in the compartments at the foot of the Drakesnberg. The principal are the Inxu or Wildebeeste, the Mooi, the Pot, and Tsitsa, which converge towards the Maclear boundary and produce the important Tsitsa River.

In the north the Luzi unites with the Tina, a tributary of of the Umzimvubu, or St. John's River, an important feeder in the north-east, being the Kenigha which rises in Mataiele.

A most interesting feature is almost all the rivers is the peculiar effect which the terrace-like structure of the country has upon their courses. The soft strata overlying a bed of hard Molteno sandstone are cut away by the river to form a plain, usually more or less swampy, and over this the river progresses in most complicated curves and windings, with cut-off loops. Such meanders are extremely well seen for example, along the Inxwana River, on the farm Chepstowe, and lower down again at a point a few miles east of Ugie, also on the Nxanxa River at Katkop; the size of the loops is, however, always small. These swampy valley bottoms are very difficult to cross at times, and are usually impassible in the wet summer season, hence the roads are carried as far as possible along the higher ground of the watersheds, and the drifts are made where hard rocks appear in the beds of the streams.

After winding about in this manner the river reaches the termination of the bed of hard sandstone and tumbles down into a gorge, forming a waterfall. Such features are characteristic of nearly all the rivers, and waterfalls are numerous in their passage through or over the belt of high ground forming the Zuurberg. One of the finest of these along the Tsitsa River is situated on the farm "The Falls," just before that river joins with the Mooi; it must not be confounded, however, with the magnificent waterfall on the same river farther down, below Shawbury. Owing to the high rainfall, falling mostly during the months from December to March, and amounting on an average to from 30 to 45 inches annually, the rivers are perennial, and there is an abundance of water

in the smallest streams even in the winter. This is reflected in the verdant aspect of the hills, except at such times when the old grass has been burnt off in order to provide fresh pasturage for the winter.

## The Beaufort Series.

The uppermost division of the Beaufort series, which has been called the Burghersdorp beds, extends along the base of the Zuurberg escarpment, but, excepting in the section between Qumbu and Mount Frere, the presence of the formation has merely been determined at a number of points below the Molteno beds, in order to prove the continuity of the divisional line between the two series of rocks. The beds consist essentially of purple and buff mudstones and shales, in thicknesses of from 50 to over 100 feet, alternating with thinner bands of yellowish fine-grained sandstone, which is pale blue in colour where freshly exposed. These rocks were seen forming the lower ground within the great gorges separating the spurs on which Gulindoda, Gaka and Bazeia stand, and were examined along the cuttings of the road from Ugie to Engcobo, which descends the Myolo valley. These beds appear again in the narrow ravine of the Umga River, some three or four miles below the point where it enters the Tsolo division, while they were seen once more in the gorge of the Inxu River exactly on the eastern boundary of the small block of farms originally surveyed for inclusion in Maclear, but restored to the natives. The purple shales were met again further on at the bottom of a small tributary of the Tina, which crosses the Maclear boundary a couple of miles north of View Hill, 1,600 feet below the summit of that eminence.

From N'Tabodule the base of the Molteno beds was followed continuously below the escarpment up the Tina and its tributary the Luzi, and it was interesting to find that on the latter river the Beaufort beds made their appearance at a distance of only 5 miles from the Cave sandstone which caps the great mass of the Paardeberg, so great is the relief of the region.

Along this section and as far as the Umgano Range the strata along the junction are seldom well seen owing to soil, grass and vegetation, but here and there the purple shales show in gullies and along paths, and, of course, in the narrower ravines.

Indeed, within the area of these beds which was mapped, amounting to some 500 square miles, and of which no small proportion consisted of dolerite, the main outcrops were

formed by sandstones, and good exposures of the softer strata were confined entirely to the steep banks of the Tina River and a few of its short tributaries. A very important horizon about 1,000 feet below the Molteno beds is formed by massive sandstones between 200 and 300 feet in thickness. These rocks were noticed just to the west of Mount Frere, and form the block of high ground to the south on which the Triangulation points Red Hill and Papana stand. The zone continues to the south-west and through it the Tina River has cut a narrow gorge for a number of miles bordered by cliffs.

Approaching the Tina Bridge the sandstone rises to the east at from 1° to 2°, so that the river passes between two "gates," the left hand one being ascended by the main road to Kokstad, while the right hand one is known as Qungu Hill. Within and below this gap, over two miles in width, the river makes several large loops. The purple and blue shales are well exposed in the hill sides, but away from the valley the purple beds are usually bleached at the outcrops to a buff colour.

Limestone nodules are common in these shales, while in the sandstones there are calcareous concretions which frequently weather out like small cannon-balls; in other places, where more lime was originally present, hollows are now left partially filled with chocolate-coloured earth.

At the Tina River bridge reptilian bones were found in hard bluish sandstone at several spots. The remains, which consisted of vertebrae and ribs, were those of small forms, perhaps a few feet in length, and were too friable to extract. Fragments of bone were also found at Qumbu in a ballast pit at the northern end of the town and again at a drift about 2½ miles along the main road to Katkop. Not uncommonly rolled pieces of bone are to be found in the "clay-pellet conglomerate," which is characteristically developed at the base of thick beds of sandstone, where they rest upon gently undulating surfaces of blue or purple shale.

The only remains of plants were badly preserved striated stems, probably a species of *Schizoneura*. An important point that has been kept in view during the work is the possibility of subdividing the Beaufort beds in the Transkei. With such a limited area mapped it is impossible to express an opinion, but it has been noticed[1] that from the Umzim vubu Bridge to the corner of Natal lower strata are found which differ from the Burghersdorp beds in including only a few thin layers of purple shale, the prevailing colour of the

[1] See Report on Mount Ayliff further on,

finer grained rocks being pale or dark bluish-green. It is, therefore, suggested that, in view of the similarity of the succession to that between Queenstown and Stutterheim, and again to that between Steynsburg and Rosmead, these lower beds correspond to the middle and possibly also the lower divisions of the Beaufort series, especially as the Ecca and Dwyka series have been found further eastward in Pondoland.[1]

Continuation of the work in this area however will, it is hoped, enable satisfactory divisional lines to be drawn in the Karroo beds of the Transkei, corroborating or disproving the provisional suggestions put forward in the areas examined further to the south-west.

### The Molteno Beds.

As in the Stormberg and in Matatiele this series, probably not more than 1,800 feet in thickness, consists of thick layers of coarse pebbly felspathic sandstones, separated by bluish and grey softer-weathering fine grained sandstone, mudstone and shales. Owing to this alternation of harder and softer beds the country occupied by this formation has a terraced character, the sandstones giving rise to small scarped plateaux and table-topped hills, for the shales are readily weathered, and the overlying sandstones break off in great masses along vertical joints, so that the slopes of the hills are strewn with fallen blocks some twenty or thirty feet in length at times. An interesting case is seen along the Little Pot River, on the farm Fairbridge. Here the stream has rapidly removed the soft shale below a bank of coarse sandstone and huge blocks of the latter have broken off along nearly straight joints and tumbled down into the channel, so that for over 100 yards the water flows in the spaces between sandstone blocks, and one can cross dryshod to the opposite bank.

The weathering of these coarse sandstones has been referred to in the accounts of this formation elsewhere, and there is therefore little to add. It is sufficient to remark that the surface is usually rough and broken up into numerous knobs and projections, with irregular hollows and cavities, so that the rocks frequently possess fantastic rugged outlines, resembling the weathering of the sandstones of the Table Mountain series. On these surfaces there are numerous little hollows around which for a short distance the rock is cemented with hydrated oxide of iron, due to the weathering of concretionary nodules of iron pyrites. This mineral is also found in irregular layers in the sandstone in a few localities.

[1] Ann. Repts. Geological Commission for 1901, p. 27, and 1902, p. 14.

A most peculiar feature, however, is the irregularity in the weathering of the sandstone on a large scale in different spots. While tabular profiles of the hills predominate, especially along the sides of the deeper valleys, as for example along the Inxu, Mooi, Pot and Tsitsa Rivers. there are wide areas in which these same hard sandstones give rise to slopes with smooth and unbroken outlines. Such country is undulating in character and grass-covered, while only here and there are there exposures of the underlying rocks. Indeed, in many places it is very difficult to be sure whether the formation below the surface consists of sedimentary rock or of dolerite, a difficulty which is intensified by the fact that these sandstones, though pale in tint, commonly produce a soil of a remarkably bright colour.

In the railway cuttings between Elliot and Maclear there are numerous sections showing the process of the crumbling down of the sandstones, and the development of pink and red tints in the friable mass of rock below can be studied. The soil resulting is light and sandy in texture, with numerous little pebbles of quartz weathered out of the sandstone, while the colour varies from orange to a deep brick-red. A thickness of from 8 to 15 feet of soil is not unusual, but generally the depth is very much less. Drab and grey coloured soils have been formed from the shales and mudstones, and they are clayey in character in most of the valleys. The soils of the Molteno beds are generally "sour" and poor from an agricultural standpoint. The most fertile areas are, firstly, the flat, with a good deal of alluvial soil, along the Little Pot River, west of Maclear, and, secondly, the Umga Ward, where a good deal of decomposed dolerite is found just below the surface.

These sandstones contain a good deal of felspar, usually rather decomposed, especially at outcrops, for the rocks are porous, and the felspar fragments are readily altered to kaolin. The pieces of felspar may, in cases, attain a diameter of half an inch, while in a railway cutting, about a mile to the south of Ugie Station, small pebbles of granite and graphic granite were observed in addition. The grains of quartz frequently show partial restoration of the crystal faces, and the light reflected from these facets gives the rock a sparkling appearance in the sunlight, hence the appropriate name of "glittering sandstones" given to them.

Small pebbles of white or blue-black quartz up to an inch or thereabouts in length are most characteristic of these sandstones, and some portions are so pebbly in character that they can almost be termed conglomerates.

They have obviously been laid down in shallow water as indicated by the variation in texture and the marked false bedding in the rock, but a most noticeable feature is the regularity of the beds, individual layers of coarse sandstone being traceable for scores of miles. Traces of gold have been found in most of the sandstones, especially in the coarser varieties and assays are stated to have gone as high as four pennyweights, as on the farm "The Caverns," near the Umga River, though the values found show that the distribution of the gold is irregular.

A most interesting feature of the Molteno sandstones is the occurrence in them of isolated pebbles and boulders of white or pale bluish fine grained quartzite; indeed one has not far to walk, as a rule, along an outcrop without finding one or more quartzite boulders that have been weathered out of the rock. They appear to be more common in the lower half of the Molteno beds, though, as will be mentioned later, similar inclusions are found here and there in the sandstones of the Red beds. Thus, in the cave behind the cascade of the Tsitsa River, on The Falls, there are a number of quartzite inclusions in the sandstone forming the roof of a small coal seam; one of these is a foot in length.

A boulder of the same length, but flattish, was found in the sandstone cliff overlooking the Pot River, opposite the farm "Excelsior"; this shape is exceptional, for usually the boulders are beautifully smoothed and polished and generally oval in outline, in all cases, however, the corners are well rounded. Another characteristic of these boulders is the jointing which they possess, so that they are commonly broken into two or more pieces.

In a small isolated cone, two miles to the south of N'Tabodule store, there are numerous pebbles from 2 to 8 inches across, strewing the slopes, and weathered out of the basal soft fine grained standstones of the Molteno beds; they are mostly well jointed. The assemblage includes one of quartzite, veined with white quartz and a pebble of brownish fine grained felspathic sandstone.

Such quartzite boulders were observed in the extreme north-west as well as in the Umgano Range, Mount Frere.

*Subdivisions of the Molteno Beds.*—As in the area to the south-west the Molteno beds can be sub-divided into definite zones, characterised by certain prominent beds of sandstone and by coal horizons.

The most important bed is, as noticed in previous Reports, the *Indwe sandstone,* which is the first coarse-grained band met with above the Burghersdorp beds. From south-west

to north-east this prominent bed gives rise to a fine cliff, yellow or red in colour, and from 100 to 200 feet in height, and the escarpment of the Zuurberg owes its prominence to the presence of this layer of massive sandstone. Wherever a river passes over its outcrop there is usually a waterfall, below which the stream is hemmed in by the prominent cliffs due to the protection which the sandstone has afforded to the softer strata beneath it.

These underlying beds consist of soft greyish fine grained felspathic sandstones, with a few bands of bluish to greenish mudstones, while in several localities coal makes its appearance, being thus on the horizon of the Indwe seam. Even where a seam has not been developed, there is usually an irregular band of carbonaceous shale present or a layer at the base of the sandstone full of patches of coaly matter and carbonised tree stems. This is well seen, for example, in the gorge two miles to the north-east of View Hill Trigonometrical Station. The thickness of the strata from the top of the Beaufort beds to the base of the Indwe sandstone varies from about 400 to 500 feet.

A short distance above the Indwe sandstone there comes the horizon of the Cala Pass and Gubenxa coals. and it is also at about this position that an important intrusive sheet of dolerite makes its appearance. This feature, which is so well developed in the southern part of Xalanga and Elliot, continues into Engcobo, Maclear and Tsolo, and hence in the great spurs of the Zuurberg, on which the Trig beacons Gulindoda, Gaka, Bazeia and Vete stand, a cliff or " palisade " of rudely columnar dolerite crowns the precipice made by the thick Indwe sandstone immediately below. North of the Inxu River the dolerite splits up into several sheets of no great thickness, while between the Tsitsa River and N'Tabodule the strata just above the Indwe sandstone are free from dolerite.

The Gubenxa sandstone of Elliot, the table-topped hills of which rise 550 feet above the Indwe sandstone, was found to be less prominent to the north-east, while on the other hand a sandstone lying between these two massive beds became more conspicuous in that direction.

Higher up in the formation a bed of sandstone was found to give rise to fine plateaux surrounding the town of Maclear, and, for example, extending onwards to the Pot River; below the precipice there is usually a seam of very impure coal.

The upper boundary of the Molteno beds has been drawn just above an unusually coarse pebbly sandstone, which

makes a prominent feature in the area under consideration, as well as in Elliott. Above it the rocks change their character, the sandstones becoming finer-grained and yellower, and the shales and mudstones acquiring red and purple tints. The outlines of the hills are different also and the slopes become more even in character, in sharp contrast to the terrace produced by this uppermost of the Molteno sandstones.

Below this sandstone it is true that a thin layer of purple shale a few feet thick is found, which is very persistent, but it is only above the cliff that the highly coloured shales of the Red beds can really be said to commence.

The escarpment of the terrace is found at the foot of the Drakensberg and its spurs from the Gatberg Peak in the south to Mount Fletcher in the north, while the pebbly sandstone forms a basement upon which stand the Prentjes Berg and Paarde Berg. Small outlying masses form Philip's Kopje, near Ugie, the high ground overlooking Maclear, and the isolated knob of the Kat Kop.

*Fossils of the Molteno Beds.*—Blocks of silicified wood are numerous, especially in the lower half of the formation. To the north-east of Maclear, on the farm Hulley Hill, there is a trunk of a tree now silicified and about 3 feet in diameter, embedded upright in sandstone. About 300 yards to the south of this a nearly upright trunk, almost 2 feet in diameter, projects out of the ground, while broken off portions of the same are found round about, so that the stem must have been many feet in height originally.

Plant remains were found at a number of points, but, owing to the scarcity of exposures of the softer strata and especially of fissile shales, collections were only made from a few localities, notably at Maclear itself.

*Thinnfeldia*, *Taenioptaris* and *Baiera*, *Stenopteris*, *Callipteridium* and *Phoenicopsis* were all found, also a specimen of the rare genus *Pterophyllum*, while at the drift over the Luzi River, near Mount Fletcher, a number of impressions were obtained, evediently of the fructifications of plants.

*Coals of the Molteno Beds.*—Thin seams of coal have been found at a number of points in the area in question, but it is only in the Gubenxa district, the eastern extremity of the Elliot Division, that a workable seem has as yet been discovered.

This region was described in the Report for 1903,[1] but within the last few years a number of openings have proved the extension of the seam exposed in the stream-beds on Tafelberg and Newcastle, not only in the Division of Elliot itself, but in that of Engcobo, immediately to the south.

1. Pages 181-2.

In view of the importance of this work an examination was made of this recently discovered coal field, and the geology and the outcrops of the coal in this area are indicated on the map attached.

There are four separate Mining Areas, excluding those known and visited in 1903, namely, the Gubenxa, Parker's, Robert's, and the Manzamdaga areas; recently these interests have been merged in the Tembuland Coal Syndicate, Limited, Maclear.

The structure of the area is simple. The Indwe sandstone crops out along the Umtolo and Bashee Rivers, while the Gubenxa sandstone builds up the high-lying ground and forms prominent table-topped hills (Fig. 1); the strata are penetrated by large dykes and sheets of intrusive dolerite, and there are a number of narrow vertical dykes also, but of no great importance however. To the presence of these

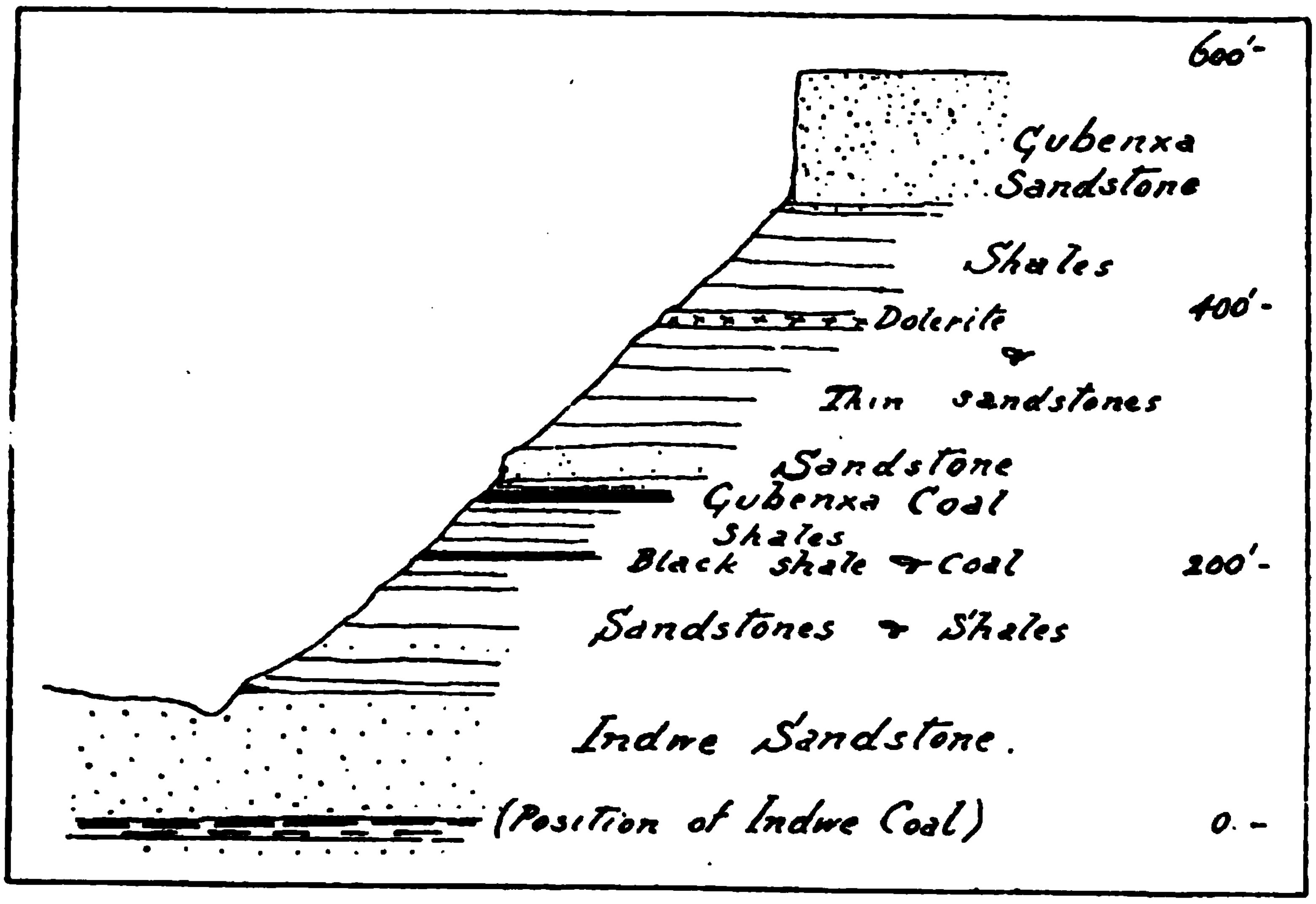



FIG. 1.—Section of strata in the Gubenxa Area, Elliot.

sheets of igneous rock is due, in great part, the semi-anthracitic character of the coals, and, as will be pointed out further on, there are many tracts which will be most unpromising to prospect, mainly for this reason.

*The Gubenxa Area.*—The coal has been opened up on the slopes of a prominent table-topped hill, crowned with the conspicuous Gubenxa sandstone, the strata having a small inclination of about 1° or 2° to the morth. On the east there rises a broad inclined sheet of dolerite, an extension of the

great intrusion seen in the gorge of the Bashee River. The seam has been opened up on erven nos. 21 and 22, but the coal is hard, and anthracitic here, owing to the proximity of the dolerite and these characters become more pronounced as the intrusion is approached; at the same time the shale forming the roof of the seam becomes extremely indurated.

At the main drive the coal is of much better quality, and the section of the seam is as follows:—

| | | |
|---|---|---|
| Shale and mudstone .. .. | Roof. | |
| Impure coal .. .. .. | 3 inches | (Workable seam) |
| *Coal* .. .. .. .. | 21–23 „ | |
| Shale parting .. .. .. | $\frac{1}{4}$–$\frac{1}{2}$ „ | |
| *Coal* .. .. .. .. | 8 „ | |
| Fireclay and shale .. .. | 14 „ | |
| Impure coal .. .. .. | 3 „ | |
| Shale .. .. .. .. | 15 „ | |
| *Coal* .. .. .. .. | 4 „ | |
| Shale .. .. .. .. | 5 „ | |
| Mixed coal and shale .. | 6 „ | |

The workable seam consists of the uppermost 3 feet of this section and is characterised by the little shale parting towards its base, a feature which is very persistent, for it is present in each of the openings, not only in the immediate neighbourhood, but over Newcastle and Tafelberg as well.

The roof is formed of about 10 feet of shale, and this is a point of distinction from the seams on the Indwe coal horizon, where massive sandstone rests directly upon the seam. In Gubenxa, opposite the western end of erf No. 22, these shales have disappeared, and a bed of flaggy sandstone rests upon the coal, the upper member of which is only 7 or 8 inches thick, instead of 21 inches. This attenuation of the seam appears to be a purely local feature, and is not represented in the other areas; it is due to "contemporaneous erosion," such as has, for example, affected the coal at Indwe, where the upper section of the seam is absent over certain parts of the field.

The coal at Gubenxa is semi-anthracitic in character away from the great dolerite intrusion which limits the area on the east; in composition it approximates closely to that from Molteno. The following is an analysis carried out by Mr. J. G. Rose, F.C.S., in the Analytical Laboratory, Cape Town, on material which had, however, been exposed in sacks to the weather for some months, and has, no doubt, deteriorated slightly:—

| | |
|---|---|
| Fixed carbon .. .. .. .. .. | 65.54 % |
| Volatile matter .. .. .. .. | 8.12 % |
| Ash .. .. .. .. .. | 25.48 % |
| Moisture .. .. .. .. .. | .86 % |
| Sulphur .. .. .. .. ... | .69 % |

Although the Gubenxa coal is certainly the most important occurence of its kind in this part of the Transkei, it is deficient in volatile matter, though it burns satisfactorily in the grate or in the fire-box of an engine without clinkering. The top and bottom layers of the seam are hard and rather stony and impure in character, while the middle portion representing the best quality is somewhat friable and " tender."

The area, however, over which the coal appears to persist, is, as far as can be judged, satisfactory. On the south the field is limited by the outcrop, on the east and north by the big dyke, beyond which no work has yet been done in order to prove the extension of the seam. Throughout the area a thin sheet of dolerite, an offshoot of the big dyke, intervenes between the coal and the Gubenxa sandstone. On the east it is over 100 feet above the coal, but towards the west it gradually descends, and near the erven Nos. 31-33 and 34-37 it is so close to the coal horizon that the seam will almost certainly be too anthracitic to be of value. It has been pointed out that a sheet has invaded the coal on Newcastle; this dolerite is probably the extension of the intrusive layer at Gubenxa. In a westerly direction, therefore, the field is also limited.

The intrusion can be followed continuously round below the table-topped ridge forming the boundary of the district (upon which beacons 33 and 34 stand) and the seam has been opened up beneath it at several points on *Parker's Area* (in Engcobo). The seam has the same thickness here as at Gubenxa but the lower coal is hard and stony; it is only to be expected that the coal will be anthracitic in character, for the dolerite sheet overlying it is only separated from it by from 35 to 50 feet of strata.

At the head of the valley, however, the sheet rises to join up with the great intrusive mass of Ralili overlooking the Bashee River. On the opposite side of the valley there lies *Robert's Area* where sections of the seam have been exposed in drives at the base of a conspicuous flat-topped ridge, the thickness of the coal remaining as before.. The coal is an anthracite, but since there is no dolerite above it and since it seems hardly possible that the great intrusive sheet visible further to the east occurs immediately underground, the suspicion is raised as to whether the anthracitic character of the coal is not perhaps an original feature rather than one due to igneous alteration.

If this be the case, namely that the semi-anthracitic or anthracitic character represents a feature inherent in the coal, then we have an explanation of the general absence of thoroughly bituminous coals, not only in Gubenxa but throughout the Stormberg and Transkei; a view which receives strong support from the examination of the Welsh Coal Fields[1] A coal originally semi-anthracitic in character would therefore only require a comparatively small amount of subsequent alteration to convert it into an anthracite, and this would explain the apparently considerable and disproportionate effect of dolerite intrusions, even when of no great mass and when separated from the seam by from 50 to 150 feet of sandstones and shales.

Anyway the coal in this area is of inferior quality and, since a mile to the east and again to the south there is a thick sheet of dolerite just a little below this horizon, it is unlikely that better coal will be found along the spur parting the Bashee River from the Umtolo. The same condition holds to the east of the Bashee gorge as well. A little to the west of the Trig Station Ralili the Gubenxa seam has again been opened out, showing the same section as elsewhere; this is known as the *Manzamdaga Area.* The lower seam is very hard and the coal is practically an anthracite; this is due to the great inclined sheet of dolerite seen immediately to the south and east of the opennigs. Further work in a southerly and south-westerly direction is therefore barred. About ¾ of a mile to the north carbonaceous shale with plant remains appears upon what seems to be the coal horizon.

Between Manzamdaga and Newcastle there lies an unprospected piece of country, undulating and grass-covered and crossed by a few narrow dykes, to which attention might be turned sometime.

A seam of carbonaceous shale and impure coal is found a short distance below the Gubenxa coal at several points; below this course the Indwe sandstone forming the precipitous banks of the Gubenxa Stream, and beneath the sandstone impure coal is stated to occur just within the boundary of the Engcobo Division.

Thin coals on the same horizon appear close to the bed of the Umga River on the Maclear—Tsolo boundary. For example, at the drift close to the junction of the farms Killarney and Glen Cole there are two small seams corresponding to those at Gubenxa, the upper one very impure, while the lower contains only from 5 to 6 inches of hard coal; the Indwe sandstone appears a little below in the river bed. Both little seams are exposed further up the river again on the adjoining

---

[1] Memoirs of the Geological Survey of England and Wales. The Coals of South Wales, chap. ix., 1908.

farm Wheatfield, where the upper is about 8 inches in thickness. A sheet of dolerite has been intruded throughout this area upon a horizon close above the coal, which is therefore anthracitic in quality.

Coal has been reported to exist on the Tsolo border close to the main road from Maclear to Tsolo, presumably on this same horizon, but this locality has not yet been examined. The Indwe seam is represented by an impure coal immediately below the Indwe sandstone at the waterfall on the Tsitsa River ("The Falls"), while the Gubenxa coal is poorly represented a few hundred yards away. A higher seam is badly seen on the farm Hulley Hill, where it can be traced to the Pot River Drift on the main road, while it makes its appearance again at Maclear in a stream leading into the Mooi River about half a mile north-east of the Railway Station. Some years ago coal was extracted at this spot and burned locally, though, as it was taken from an outcrop, it was of inferior quality. A higher seam is also found at Maclear just below the sandstone bed forming a scarp to the high ground north of the town. It is well exposed in the road cuttings and has been referred to in the Annual Report for 1902, p. 16. It appears further to the north at intervals along the bridle-path which leads from Maclear across the farms Plateau and Frank Skead to Tsitsana.

Between the Tsitsa River and N'Tabodule there is a plateau of no small extent to which attention must be drawn, for the strata are particularly free from dolerite intrusions along the horizons on which the Gubenxa and Indwe seams may be expected to occur, a rather uncommon feature indeed in this dolerite infested country.

On the north-eastern flank of the Umgano Range, overlooking the Mandalini Basin, a seam has been opened up at several points on the Gubenxa coal horizon. Although there is only about 8 inches of coal available out of several feet of carbonaceous shale the locality deserves further prospecting, for the strata are fairly free from dolerite intrusions and it is possible that the coal may thicken at a distance from the existing drives.

This portion of the Transkei, it must be noticed, is situated far away from existing railway lines and it is therefore an expensive matter to obtain coal from either Indwe or Natal. Seams which it would be impossible to mine with railway communication into Natal, might possibly be of value locally, though to a limited extent, a matter which is worthy of consideration on account of the increasing scarcity of timber in certain parts of the Territories.

## THE RED BEDS.

The Red beds maintain in this area the characters which are so typical in the region to the west, while the thickness of the series as measured at a number of points is uniformly 1,200 feet.

They consist of beds of yellow or buff sandstone, in places rather thick and prominent, separated by shales and mudstones purple, red, blue and buff in colour. The best sections are only seen along roads, and fortunately there are two excellent cuttings in which the full succession is shown and in which the rocks can be studied in the fresh condition. These are the ascent from the Pot River to Tent Kop in Maclear and the descent of the Pitsing at the head of the Luzi River in Mount Fletcher.

The first shows predominating purple and red shales, mudstones and soft sandstones, often of remarkably brilliant colouring, and the cuttings indicate, what has been emphasized in former Reports, namely , the partial or complete bleaching of the tints of these beds on weathered surfaces. Hence, except in gorges where the soil is thin or absent, or where the rocks have been exposed by landslides or in artificial exposures, a very imperfect idea of the true nature of this formation will only be gained. The bleaching of the beds is usually so considerable that the natural exposures leave one with the impression of purplish beds at the summit of the formation, represented again, though poorly, toward the base and with several hundreds of feet of buff and yellow sandstones and shales in the middle of the sequence. Splendid sections are however seen in the magnificent gorges from 800 to 1,000 feet in depth at the headwaters of the Pot River on the farms Grosvenor, Dunraven, Charny, and Labyrinth, for example, the boundary with the Cave sandstone being here well defined as a rule. A similar fine section is seen in the Pitsing road cutting and on the hill sides of the ridge forming the boundary of the Maclear Division adjoining.

The brilliancy of colouring of the softer beds is often so intense that it has been proposed to make use of such material for the manufacture of paints; beds of such a nature have been opened up, for example, on the farm Waai Nek in Maclear.

Coarse grits and occasionally pebbly sandstones occur at the base of the Red beds, and not uncommonly there are found boulders of quartzite, mostly felspathic, like those in the Molteno Beds. They are numerous on the farm Waai Nek, Maclear, where one of about a foot in diameter was obtained half way up in the formation.

Of the sandstones the most prominent beds are nearly white in colour and in places contain nodules of iron pyrites

or marcasite. A layer crowded with such nodules, each from half a pound to two pounds in weight, occurs in such a sandstone on Waai Nek. Many of the sandstones are yellow or buff in colour but when fresh are found to be red; they are commonly full of porous patches or small hollows which represent spots originally rich in calcareous material, here and there occur limestone nodules.

Clay-pellet conglomerate is not uncommon at the base of sandstone layers. One band about a foot in thickness on the farm Waai Nek is pale bluish-green in colour and is full of fragments of mudstone with small limestone lumps, quartz-pebbles and a few fragments of reptilian bones.

Fossils are scarce in this formation, though a large reptilian bone 2 feet in length was found embedded in sandstone on Waai Nek and fragments of bone were picked up at several points on the hill sides of the Tsitsana Native Reserve.

Fossil wood is obtainable here and there, usually the common grey-black variety, but sometimes ranging from semi-transparent and colourless to yellow or bright red in tint.

## THE CAVE SANDSTONE.

The Cave sandstone remains as before the variable member of the Stormberg series. In the northern part of the area its characters are normal except about Tent Kop, but in the south-western corner of Maclear its behaviour and relationships both to the Red beds and to the overlying Volcanic rocks are in places extremely peculiar. For this reason in the description the northern area will be considered first. The Cave sandstone throughout this region however possesses very uniform lithological characters, similar to those in other areas already described. The bulk of the sandstone is white to creamy in colour, but in places, especially on nearly flat bare surfaces, the rock is grey or black externally due to growth of lichens, etc. Here and there the sandstone has a deep pink or red colour especially towards the base of the formation, a feature which is well seen in precipices or in caves, and such sections indicate therefore that the original colour has been pink but that its hue has been destroyed at the outcrops by weathering.

The Cave sandstone throughout the district is a massive bed usually a few hundreds of feet in thickness. The basal portion is commonly well-bedded but the middle is more massive and shows a great tendency to form peculiar pillars and buttresses, while the upper portion gives rise to rounded and smooth surfaces more or less grass-covered. The weathering is however erratic and hence the peculiar and uncommon scenery which is produced by this peculiar stratum of

rock. There is no doubt that the rock behaves very variably in its mode of weathering according to its position and environment. Thus at one point it forms smooth rounded surfaces and the stratum appears devoid of bedding planes; on either side, however, the rock is as well-bedded as any sandstone and this stratified character is almost invariably best seen in vertical continuous faces of rock unobscured by vegetation, or else in overhanging ledges and in caves. It is probably due in great part to this remarkably sudden variation in character, apparent rather than real, that certain puzzling features are brought about simulating unconformities to which reference will be made further on. There is no doubt however that at a number of points the Cave sandstone rests unconformably upon the Red beds, though this is confined to an area in which there has been much disturbance of the beds, evidently closely connected with volcanic action. Often the Cave sandstone exhibits false bedding and this character is finely developed in some large masses at the back of the triangulation station "The Klip" in Mount Fletcher where the angles of various laminae are remarkably high. In the sandstone there are usually numbers of pyritic nodules, which upon weathering produce rounded or more commonly cup-shaped forms in which the sand grains are bound together with oxide of iron. The Cave sandstone is generally very fine-grained in character though in a number of localities somewhat coarser varieties were found, at times indeed approaching closely in texture some of the Beaufort and Red beds sandstones.

A section (No. 2559) of the sandstone from Rocky Dell, Maclear, shows the following features under the microscope. The rock is composed of grains from .05 to .08 mm. across of quartz and felspar, the former predominating. They vary in outline from sub-rounded to angular and are sometimes elongated splinters with sharp edges. Some of the quartz grains are quite clear, others contain needles of rutile and dusty inclusions. The felspar consists of orthoclase and plagioclase, either fresh or clouded—and kaolinised; microcline is absent. There are flakes of somewhat altered biotite mica, muscovite mica, and a good deal of secondary white mica (sericite) in the felspars, around quartz grains, and sometimes within the quartz itself. A characteristic feature of the Cave sandstone is the presence of grains of zircon and in the slide there are a number of worn crystals of this mineral, together with some colourless garnet, and some grains of rutile. The groundmass of the rock is fairly abundant, cloudy and dusty and probably for the most part kaolin; in places it has a pinkish colour corresponding to the pink mottling of the sandstone in the hand specimen.

Another section (2566) from the summit of the Hlankomo Mountain, Mount Fletcher, shows nearly similar features, but microcline felspar is present in addition and the rock contains somewhat more mica.

The thickness of the Cave sandstone varies considerably. In the north-east it is thick where it caps the ridge terminating in the "Castle Rocks," and on Paarde Berg and the Hlankomo it is no less than 860 feet in thickness. Here it forms rather smooth rounded summits from which several extraordinary spikes of sandstone project, while it forms a splendid bright yellow precipice rising into a number of minor pinnacles overlooking the Pitsing Basin. When followed westwards along the ridge forming the boundary between Maclear and Mount Fletcher the sandstone rapidly becomes thinner; and the same is the case at the head of Tokwana Valley where it thins to only 50 feet. Again in the Tsitsana Reserve the bed is 300 feet thick at the eastern beacon of Hartington and only 100 feet in the kloof on Sejoseng's Location. There is evidence to show that this diminution of thickness is in part due to the pouring out of the basaltic lavas whereby the deposition of sediment was hindered in a westerly direction but not entirely prevented, as is shown by the two beds of sandstone found intercalated in the lavas for a considerable distance. This same feature is seen around the Tent Kop, for, at the ascent on the main road to Tiger Valley, the Cave sandstone is probably not more than 30 feet thick, its minimum value in the area, while westwards and southwards it thickens considerably. The character of the formation is abnormal however around the Tent Kop a feature which is due to earlier volcanic outbursts than have been observed anywhere else in the Drakensberg, for on the farms, Glen Airy and Motley, a bed of volcanic ash actually underlies the Cave sandstone.

This occurrence is indeed unique, the purple shales and mudstones of the Red beds passing upwards without any stratigraphical break into purple stratified ash. The beds are here affected by a monoclinal fold and at the beacon common to the two farms the ash is from 150 to 200 feet thick, dipping below the Cave sandstone which is in turn capped by a small thickness of basaltic lavas. When followed along the hillsides the zone of ash thins out in either direction, but the Cave sandstone itself is full of small angular inclusions of indurated sandstone and shale so that the rock in places becomes a tuff.

At the beacon overlooking the homestead on Halifax a zone in the sandstone is crowded with nodules of limestone and the rock shows a pseudo-brecciated structure due to the fact that the bedding planes over a small area dip in a different direction to those in neighbouring patches. In the valley

running from Motley to Zebra Dell there is a large volcanic neck evidently the origin of the disturbance, for tuff is seen in the bed of the stream breaking the continuity of the Red beds on the right bank while hard sandstone with peculiar disturbed bedding crowns the overhanging ridge. The Cave sandstone seems to rest unconformably upon the Red beds, the uppermost portion of the latter appearing to be missing on the northern corner of Zebra Dell.

A slight unconformity, connected no doubt with the monoclinal fold, appears in the Tent Kop itself both at the base and the top of the Cave sandstone, and the latter varies from 240 feet in thickness on the west to 50 feet on the north. The northern slopes of the Tent Kop may mark the site of a volcanic neck for the Cave sandstone contains fragments of sandstone and shale, is indurated in places and dips inwards occasionally at angles up to 15°, while on the north-east the basalts form a tongue passing down into the purple shales and frequently show brecciated structures.

The cone of the Tent Kop is however an outlier of lavas associated with a thick band of tuff, which is not represented among the volcanics round about.

Right down in the valley on Midlothian there is a little knob of pale sandstone on which a house has been built and which is in contact with red shales on one side and alluvium on the other; if it is Cave sandstone its position is most peculiar. An uncommon feature was the occurrence in the sandstone of a large quartzite boulder beautifully smooth and oval in outline and about 9 inches in length. The occupier of the house, Mr. Pienaar, informed me however that he had obtained similar boulders from the Cave sandstone at the base of the Tent Kop a mile to the south. South of the Tent Kop the Cave sandstone caps a plateau overlooking the Pot River Valley and is very well stratified; under the Drakensberg, however, it forms once more a massive bed of sandstone, about 300 feet in thickness on the farm Labyrinth.

From this point the width of the Cave sandstone outcrop broadens until it forms a plateau with rather uneven surface from 6,000-6,500 feet above sea-level, separating the valley of the Pot from that of the Mooi River, and in which the sandstone covers, roughly speaking, about 25 square miles. Near the summit of the formation, which has here thickened to over 600 feet, a thin basalt flow is found on the farm Springton and at the easternmost beacon of Pondo Gates.

The Prentjes Berg, overlooking Ugie, is a great outlying cake of Cave sandstone, 4 miles in length, on a pedestal of Red beds. On its southern face there is a fine cliff, in which the basal portion of the sandstone, here 800 feet thick, is bright red in colour and finely stratified. On the north-western face yellow sandstone makes a smooth wall-like feature,

below which the uppermost purple and red shales of the Red beds make a conspicuous outcrop.

Another outlier forms the south-western extremity of the ridge of Red beds on the left side of the Gatberg or Inxwana River, the greater portion falling within the farm Pontresina. Near the summit of the Cave sandstone there is a bed of tuff —pale yellow in colour—into which the sandstone grades; it is not more than 10 or 12 feet thick.

This outlier is of interest on account of its situation relatively to the Red beds. At several points the base of the sandstone falls below the level of the purple shales and sandstone of the Red beds, and to the north-west the ground rises and is still formed of rocks belonging to the latter formation, with some intrusive dolerite. Where the Cave sandstone is present about 300 feet of the Red beds are missing, pointing to a local unconformity. Beneath the Drakensberg, however, from Mooi River Head down to just within the Elliot division the formations are very much disturbed, and the strata are frequently found to be dipping now in one direction and now in another, sometimes at fairly high angles. It is most important, however, to notice that the basaltic lavas close at hand are absolutely undisturbed, proving that the earth-movements took place during (probably also somewhat previous to) the deposition of the Cave sandstone, but had ceased by the time that the area became flooded with lavas.

The disturbances in the Cave sandstone commence on Elephant Rock, which derives its name from a remarkable prominence of sandstone in the middle of the farm. From this point southwards dips of from 10° to 30° are not uncommon, now in one direction, now in another, while the strata are cut by some thick inclined sheets of dolerite.

On the farm Morvern the sandstone possesses in places dips of from 40° to 60°, and there are many fine sections in illustration of this in the maze of deep kloofs which traverse the formation. Towards the south-western corner of this farm there is a remarkably clear section in a cave showing a bed of ash, pale blue in colour, in the sandstone, and at least 100 feet in thickness, overlain by bright pink sandstone, the boundary between the two rocks being quite sharp. The occurrence is local, and the bed cannot be traced far; it has the same characters as the great bed ofash some 400 feet higher up in the series and a mile and a half towards the mountain range.

In the main gorge leading into the Wildebeeste River the Red beds are thinner than usual, and a local unconformity is found, which is better seen in the cliffs overlooking the homestead on the farm Glenelg (fig. 2), just over a mile to the south. A massive sandstone belonging to the Red beds forms a prominent ledge along the hillside, and brings out the unconformable nature of the boundary with the Cave sandstone. A

stratum of ash makes its appearance near the base of the Cave sandstone, in the floor of the valley, while to the south the formation rises suddenly at least 900 feet to cap the ridge overlooking Rondadura. The angles of dip of the Cave sandstone are higher than those of the Red beds on this ascent, but on Maloja the sandstone comes down abruptly into the ravine, where it is in contact with pebbly grits belonging to the Molteno series, the whole of the Red beds being absent. The Cave sandstone then forms an outlier on the ridge overlooking Noah's Ark Commonage in Elliot, as mentioned in an earlier Report, where it is in contact with Red beds (no great thickness, however) and Molteno grits and sandstones.

On Monzie there is a second inlier of Molteno grits and bluish shales, with a prominent band of pebbly sandstone over 100 feet in thickness, forming precipices bordering the narrow gorges on that farm, accompanied by sheets of intrusive dolerite. On the south-west there is a curious conical hill formed by a knob of pale yellow sandstone, resting on

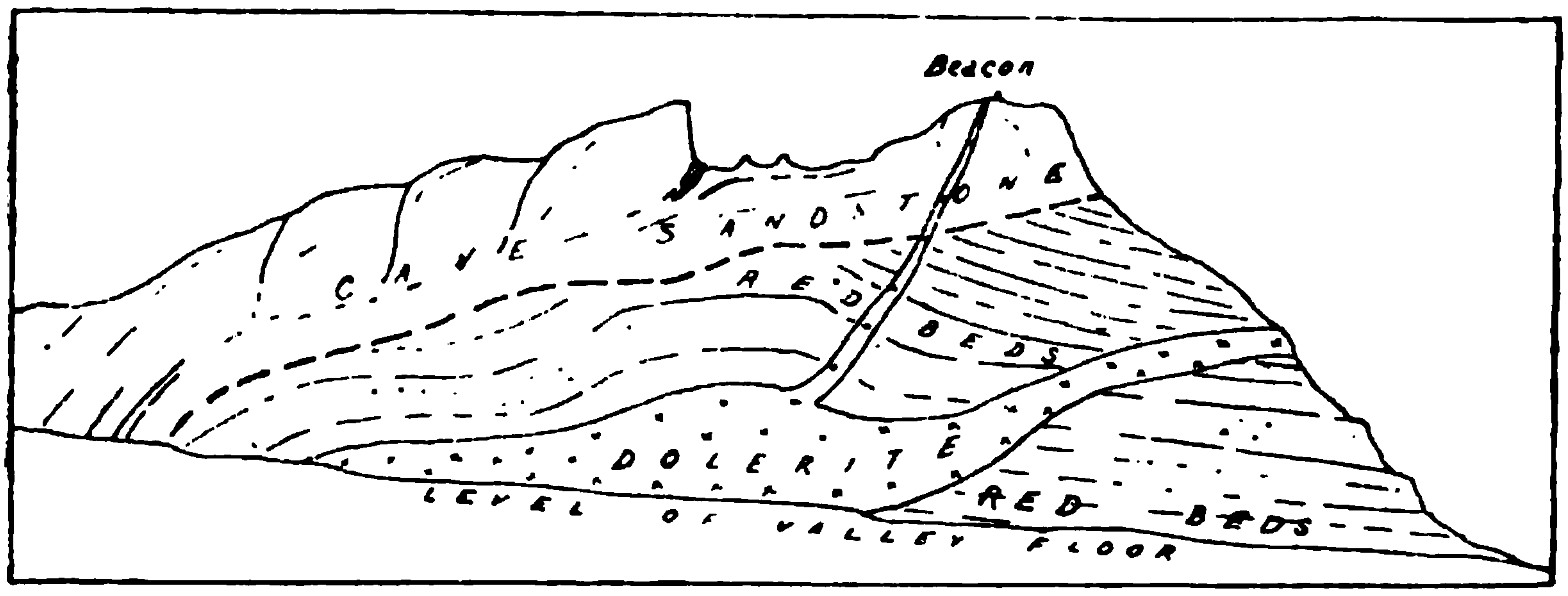



FIG. 2.—Diagrammatic view of north side of valley on Glenelg, showing the unconformable junction of the cave sandstone with the red beds. Height of beacon above valley about 1.200 feet.

practically undisturbed Molteno beds. There are no signs of breccias or tuffs, and the feature is probably to be explained as an outlier of Cave sandstone rather than a tuff neck; if this is the case, then over 1,200 feet of Red beds are missing here, while only a couple of miles to the west, on Kathlamba, the full succession is seen from the Molteno beds right up to the basalts.

On the northern part of Monzie the Molteno beds are probably faulted against the Red beds, which are separated from the Cave sandstone by a sheet of intrusive dolerite. The sandstone, which just to the north has gorges cut in it from 300 to 400 feet in depth, thins when followed towards the west, while at the same time the Red beds swell out in thickness. The former rises rapidly towards Burgher's Nek, and the bed of ash overlying it thins out in that direction. At the boundary

between Monzie and Kathlamba the strata are traversed by a sharp anticline striking nearly north and south for over half a mile; at the south-western corner of Kathlamba the succession is normal again.

## THE ASH BED.

In the Reports for 1903 and 1904 a bed of volcanic ash was described as occuring between the Cave sandstone and the basaltic lavas in the portions of Elliot and Barkly East, adjoining this corner of Maclear.

At Burgher's Nek, leading from Kathlamba into Barkly East, the same bed of ash is very well exposed; it is bluish green in colour and about 250 feet in thickness, and rests to the south side of the pass, upon 225 feet of Cave sandstone. When followed round below the Drakensberg, it is found to thicken enormously, so that on Valletta its thickness cannot be less than 1,800 feet, while it dies out just beyond Mooi River Head in a manner that will be explained later on.

The basal portion of the ash bed is very sandy, tough and massive; it is yellowish white in colour, weathering so like the Cave sandstone in every respect that from a distance of a hundred yards and more it would be impossible to distinguish the one from the other, except where the inclusions of basalt, etc., in the former are large and become conspicuous on the weathered surfaces.

In places the junction between the Cave sandstone and the ash is sharp, as for instance on the northern end of an outlier which caps the high ground between Lonely Glen and Cromarty. At the southern end of this patch the ash is seen to be well stratified in a fine cliff section, layers being marked out by the abundance or sparcity of the included fragments.

The great bulk of the ash forms slopes a little darker in tint than those composed of the Cave sandstone; they are often bare and naturally rougher in surface owing to the inclusions which stand out by the weathering away of the matrix in which they are set. When fresh the ash is light blue-grey in colour, but the tint is brownish or reddish wherever the rock is weathered. It is remarkably uniform in texture throughout the area, while a rude stratification is not uncommon. About the centre of the farm Valletta, along a certain horizon and through a considerable thickness, the ash contains abundant large masses of compact and amygdaloidal basalt up to 4 feet in length. Generally the inclusions do not exceed a couple of feet in diameter. A very interesting point is the abundance in places of fragments of the underlying Molteno sandstones, which have evidently been torn off from below and thrown out by the volcanoes in the neighbourhood. Such boulders are extremely numerous at the summit of Burgher's Nek, where

they have weathered out of the ash and strew the surface of the ground. Many exceed 2 feet in diameter, but several were noticed no less than 5 feet across. Along with them were observed blocks of pre-Karroo quartzite, pale bluish-white in colour; some of the smaller ones are partially rounded and probably represent portions of pebbles. The great bulk of the inclusions, however, consist of fragments of sandstone, blue and red shales and sandstones derived from the Stormberg (and Beaufort) series. The ash is identical in every respect, except in its rudely bedded character with the tuffs or ash which is found filling the larger volcanic necks, such as that on Elephant Rock, for example; indeed the latter are obviously the source of the materials composing this extensive deposit.

Along the lower boundary of the main outcrop the Cave sandstone dips in below the ash at from 5° to about 40°; more commonly at from 10°—20°.

At one point in the gorge, about a mile above the old ruin on Valetta, the junction between the two formations is a vertical one, as shown in a cliff face between 150 and 200 feet in height. The actual contact is visible in the bed of the stream, where the junction is beautifully sharp. The Cave sandstone is here horizontal, but at the end of the spur it makes a sudden flexure. To the south the Cave sandstone passes in below the ash at an angle of 15°, while to the north the same feature is seen, only the angle is 40° for a short distance, bringing the base of the ash to the summit of the high ridge in that direction.

From the evidence it appears that owing to subsidence prior to and during the volcanic outbursts the ash collected in the resulting basin-shaped depression, round the rim of which were situated a number of volcanic necks, from whose throats fragmental material was being ejected. The occurrence on Valletta may well mark the position of a neck, on the extreme edge of the basin, the remainder of the pipe being merged in the great area of ash to the west.

It has been noted that the ash is succeeded by the basaltic lavas which build up the escarpment of the Drakensberg. At one point in the northern corner of Kathlamba a thin band of flaggy sandstone, about 40 feet in thickness at the most, intervenes between the two formations, and passes downwards into ash. The upper boundary of the ash runs along the base of the basaltic cliffs, maintaining an altitude of from 6,900 to 7,200 feet above sea-level, while the base of the Cave sandstone from Elephant Rock northwards to Rocky Dell, runs at the altitude of about 5,700 feet. Between these two points the Cave sandstone and ash vary in thickness in a regular but complementary manner, being 500 feet and 700 feet thick respectively in the south.

On Snowy Side, however, a bed of basalt not more than 50 feet thick, in places vesicular, appears in the ash near its summit, and as it is followed northwards increases, with the addition of other lavas, until on Rocky Dell this zone is no less than 450 feet thick. At the same time the Cave sandstone has increased in amount to 700 feet, and simultaneously the whole of the ash-bed up to the lava intercalation has thinned out and disappeared within the distance of about 5 miles. At the corner beacon, common to Rocky Dell, Glen Benno and Copeland, the base of this group of lavas is split up by a bed of yellow sandstone, 40 feet thick, separated from the Cave sandstone by 50 feet of decomposed slightly amygdaloidal basalt.

All this shows that, while the Cave sandstone accumulated freely in the north, followed bv lava flows, the ejection of ash was so considerable in the south that the full development of the sandstone was prevented in that region, and that it was only at a slightly later period that lavas commenced to be erupted there.

The very uppermost section of the ash bed can be followed along the mountain flank from Snowy Side across Mooi River Head, but over Mount Hope and Rocky Dell the band is rarely exposed, and beyond the Pondo Gates no exposures of it could be found. On Snowy Side the top of this upper ash-bed is visible, and proves to be a very fine-grained variety, red to reddish purple in colour, full of little ovoid lumps of red mudstone. It appears to contain a good deal of deeply weathered volcanic matter, either fine ash and dust, or perhaps it has been formed from the soil produced by the weathering of lavas erupted in another locality, but not far distant.

About the middle of Rocky Dell a small ravine furnishes a a complete section of this band, about 120 feet in thickness. The base consists of grey ash, resting upon amygdaloidal basalt, and this becomes redder and gets finer grained upwards, passing at 80 feet into a brick-red sandstone, with which is associated a small amount of shale. The whole is overlain by compact lavas.

The great ash-bed at the foot of the Drakensberg in Maclear is continued into Barkly East, down the Sterk Spruit Valley, as described in the 1904 Report. From the comparatively small thickness of the bed on such farms as Glen Orchy and Ben Voirlich, in Barkly East, it is clear that the basin of subsidence in which the bulk of the ash collected was limited to Maclear alone, though the fragmental material was spread upon the Cave sandstone in a fairly even layer over a considerable area in the neighbouring districts.

## THE VOLCANIC NECKS OF MACLEAR.

There are a number of volcanic necks in this area, confined to the belt of rough country produced by the spurs of the Drakensberg; of these quite a group is situated in the highly disturbed region in the south-western corner of Maclear. Two of these necks are of considerable size, but the rest are all much smaller. It will be convenient for description to take them in order from south to north.

No. 1 is the curious peak known as the Gatberg, on the Elliot boundary, situated along the axis of a prominent anticlinal flexure, or, perhaps more correctly speaking, a very elliptical dome in the strata.

The Gatberg is a plug of hard tuff, yellow in colour and approximately 100 yards by 40; the apex is pierced by a large window-like opening, conspicuous from afar, the presence of which has given the peak its name.

Excepting on the south side, the material is a typical breccia, full of angular or semi-rounded bits of Cave sandstone principally, with a few fragments of shale and inclusions of basalt; in places these latter are from one to two feet in size. On the south side of the neck the junction dips steeply inwards, and the Red beds' sandstone at the contract, which is here nearly horizontal, is brecciated.

No. 2. On the western boundary of the farm Maloja there are coarse tuffs in contact with sandstones which seem to belong to the base of the Red beds, and this material becomes more sandstone-like in character as it is followed into Elliot, where the mass can be traced down the hillside for several hundred feet. The whole appears to be a neck partially filled with tuff, into which great masses of Cave sandstane, more or less broken, have foundered.

No. 3, which is less than a mile to the north of the last named, is a prominent knob of hard yellow sandstone, pale bluish when fresh. On the east side it forms a cliff, in the face of which there are seen several bands of breccia running through the rock. That these are not merely zones along which crushing has taken place, although there are fine slickensided surfaces as well, is shown by the small quartz pebbles in the matrix derived, no doubt, from the Molteno beds, which are close at hand. Quartz pebbles, indeed, are not uncommon in these masses of tuff, which are almost indistinguishable from sandstone.

An included block of basalt, somewhat decomposed and about 10 inches in length, was observed here as well. At the base of the cliff there runs a narrow dyke of dolerite, which sends a narrow tongue into the tuff at one point.

No. 4. Half a mile away, also on Maloja, there is a typical pipe, showing rounded hummocks of sandy rock, becoming a breccia in places; no igneous fragments were noted, however. The mass is cut through by a sill of dolerite, so minutely joined that it was found impossible to procure a hand specimen showing a perfectly fresh surface.

No. 5 is a plug of tuff, exposed along the river bank close to the north-eastern boundary of Maloja. The surrounding strata are very much disturbed, dips of 60° occurring next to the pipe, and the latter shows a nearly vertical contact, about 200 feet in height, with the sedimentary rocks.

No. 6. The eastern beacon of Maloja is situated upon a prominent knob of sandstone, rising from a pedestal of Red beds, and recalling in its habit the peculiar Kiba Hill in Herschel.

While the strata forming the slopes show a moderate dip towards the north, the yellow to greenish material composing what has been taken for a plug exhibits a fine banding, dipping at about 50° to 60° near the exterior, and increasing to 75° towards the interior of the mass. This fine banding follows concentrically the edge of the plug, right round it as far as the exposures allowed of its being traced. Only at one point on the south-eastern side were there a few veins of breccia running through the material. From its habit, however, it is much more like a plug of sandy tuff than an outlier of Cave sandstone. Along the ridge about 100 yards to the north-east, there is a smaller mass which shows rather similar features and which is probably of the same nature.

After leaving this group of volcanic necks on Maloja no volcano is met with for some distance, though the layers of ash in the Cave sandstone on Glenelg and Morvern point to the presence of necks as yet unlocated.

No. 7. On Elephant Rock an exceptionally large example was, however, found, just over a mile in length from north to south, and not quite half a mile across. On the east side the Cave sandstone dips at an angle of about 5° towards the tuff which fills the pipe, and it surrounds the latter on the north side, where the sandstone is undisturbed and lies horizontally. The same is the case on the west, where the tuff abuts against a cliff of horizontal sandstone; the junction on the south-west side is also steep, but the boundary in the extreme south is ill-defined. A small ravine cuts through the pipe, and tuff is found from the river bed up to the summit of the adjoining ridge on the north bank, a vertical height of 500 feet.

The material filling the pipe is identical in every respect with that composing the ash-bed, which is exposed on the flanks of the Drakensberg, less than a mile distant, and there can be no doubt that this vent on Elephant Rock must have contributed largely towards the formation of this thick deposit of fragmental material.

No. 8. A large but elongated neck occurs below the escarpment on the farm Copeland, having a length of close upon a mile. It is surrounded entirely by Cave sandstone. The latter has a slight inward dip on the south, but elsewhere it lies undisturbed; the walls of the pipe, that is the junctions of the sandstone and the filling, are everywhere steep. The pipe is filled with a massive bluish-green tuff, like that visible on Elephant Rock.

No. 9. Quite different in character is a neck situated on the farm Coningsby, and surrounded by Cave sandstone. It is located on the ridge between two streams, along the crest of which it extends for half a mile. Towards its northern extremity its outline makes a bulge, and in this portion, where it has been cut through by a stream, the junctions with the Cave sandstone are practically vertical.

The rock plugging the neck is almost entirely a fine-grained porphyritic basalt, which at the northern end shows a prismatic structure, with the columns irregularly directed. Thin sections (2561-3) show under the microscope a very fine-grained groundmass of minute granules and prisms of augite and laths of plagioclase felspar set in a colourless glassy base, brown in places, with small spots of iron ores. Through the groundmass there are scattered phenocrysts and crystal aggregates of plagioclase felspar (labradorite, and crystals of augite, while there are few serpentine pseudomorphs sometimes moulded on the felspar, probably after olivine.

In the river-bed the igneous rock gives way to a small patch of dark green basic tuff, full of fragments of compact basalt.

No. 10. On the farm Pelham a small tuff neck is exposed in the road-cutting, near the summit of the ascent from the Pot River to Tent Kop. It is about 50 yards in diameter, and is surrounded by the basal portion of the Cave sandstone. The junctions with the latter are vertical, and the sandstone is in places brecciated along the contact.

This is one of the Tent Kop group of necks, to which attention has already been directed. A small tuff neck is seen on Ferngrove; a larger one has been described already on Zebra Dell, while two problematical tuff necks occur, one on the above farm and one on Kingsford, overlooking the ravine of the Upper Tsitsa River.

No. 13. A small neck was observed in Sejoseng's Location, in the Tsitsana Reserve, and is of interest as being the only pipe in this area which is entirely surrounded by the basaltic lavas. It occurs in a small gorge leading down from the basalt plateau of Hartington, and is probably not more than 500 feet in length, and evidently narrow, for it is hemmed in by tough, coarsely crystalline basalt (doleritic lava).

The infilling material is a dark greenish tuff, full of fragments of both coarse and fine-grained compact basalt, amygda-

loidal basalt, and to a lesser degree of sedimentary rocks. There was one block of indurated Cave sandstone, and a big mass of cavernous weathering hard siliceous material, probably a baked tuff. In a few places there are bands of alternating coarse and fine tuff dipping at a high angle across the stream bed.

A thin section (2569) of the tuff shows under the microscope fragments of altered lava, with the spaces between filled with a gritty material composed of angular to partly rounded grains of quartz, some felspar, volcanic dust, etc. The lava fragments possess well-formed phenocrysts of slightly altered plagioclase felspar and a few grains of altered augite set in a pale yellow groundmass, traversed by irregular cracks, which are marked out by deep brown alteration products. The groundmass resembles palagonite to some degree, being nearly isotropic, though showing a granular structure between crossed nicols. There are numerous oval areas, composed of serpentinous matter, probably steam-holes in the lavas, filled in with decomposition products.

## THE VOLCANIC NECKS OF MOUNT FLETCHER.

No. 1. A little more than a mile from the banks of the Tsitsa River and between the main road to Mount Fletcher and the boundary of the Tsitsana Reserve, there rises a conspicuous conical hill, built up of a capping of Red beds upon a base of Molteno sandstones and shales. The apex is formed of extremely hard, sandy tuff, full of fragments of sandstone and shales, but there are some large inclusions of sandstones, while there are areas showing bedding planes, and these may possibly be large masses which have fallen into the pipe. In places there are fragments of basalt, some compact and some with small vesicles.

The neck is elongated in plan, and at the southern extremity it runs out in the manner of a dyke. The Red beds in the vicinity are much broken and shattered, so that the exact boundaries of the neck are not easily seen. A noticeable feature is the bleaching of the purple shales close to the tuff, a phenomenon which is usual along the contacts of such highly-coloured rocks with igneous dykes. A dolerite dyke cuts through the northern extremity of the pipe, and this intrusion was traced from the foot of the Drakensberg on Antelope Park, down to the Tina River bridge on the main road to Mount Frere, a distance of 45 miles, beyond which it was observed continuing towards the sea coast.

This neck in Mount Fletcher is of interest in that it is situated further away from the line of the Drakensberg than any other in this region.

No. 2. There is a volcanic neck at the head of the Tokwana valley, not far east of Mcamballala, which is almost entirely surrounded by the Cave sandstone, but one side is dissected so that contacts are seen. The pipe is nearly circular and approximately 100 yards in diameter. In the centre there is a pinkish tuff, containing fragments of lava, sandstone and shales, which has been baked into a very hard material. The marginal portion is characterised by the presence of larger masses of basalt, forming a breccia, with only a small admixture of matter of sedimentary origin. The inclusions of sandstone are mostly indurated, and the same is the case with the sandstone forming the walls of the pipe.

The volcanic rocks occur close at hand, and a fine section is seen on the opposite side of the small stream passing the neck, which shows columnar basalts resting upon horizontal Cave sandstone.

## Volcanic Fissures under the Drakensberg.

In the south-western corner of Maclear there are certain basic intrusions which, though undoubtedly linking up with the Karroo dolerites, appear to represent feeders along which some of the Drakensberg basalts may have ascended.

Indeed, in Elliot it had been found that in certain volcanic necks there were plug-like masses of dolerite or basalt, which in certain instances formed part of the Karroo dolerites of that area; in all cases, however, these rocks were compact and sometimes coarsely crystalline. It is very noticeable, too, here, as in the Stormberg, that the number of the dolerite intrusions rapidly becomes less as one passes from the Molteno beds on to the higher divisions of the Stormberg series. Indeed, they are almost entirely absent in the Cave sandstone, and only a few vertical dykes have been observed cutting the Volcanic beds. In Maclear, however, it was observed that not uncommonly these intrusions cutting the Cave sandstone and the ash-bed possess well developed amygdaloidal structures, so that in hand specimens it would be impossible to distinguish such obviously intrusive rocks from the basaltic lavas of the escarpment.

For example, on the farm Cromarty a great sheet of coarsely crystalline dolerite is seen cutting obliquely through the Red beds and Cave sandstone. An offshoot of this in the northern corner of the farm becomes finer in grain as it is followed up the ridge, and at the summit of the latter, where it cuts through volcanic ash, it is a thoroughly vesicular rock. A thin section (2556) under the microscope proves the rock to be fine-grained, composed of small prisms of plagioclase felspar and of augite, usually encroaching upon one another, though in some places there is a tendency towards ophitic structure,

while in others the augite is enclosed in the felspar. A colourless unstriated felspar fills up spaces between the other constituents, accompanied by granules of augite and large grains of iron ores. The specific gravity is 2.91, which is a little below the normal density for the Karroo dolerites.

Another example is a dyke cutting the Cave sandstone in the north-eastern corner of the adjoining farm Lonely Glen.

Over Valletta there extends a large sill of intrusive rock, which is traceable for several miles over Morvern and Glenelg, until it joins with the undoubted Karroo dolerites of the ridge overlooking the Gatberg siding; where it cuts through the ash-bed it swells out and forms dome-shaped hills; the rock is decidedly amygdaloidal in this locality. From this intrusion a dyke stretches westwards to join up with a similarly situated dolerite mass on Mount Enterprise. The southern (corner) beacon of Valletta stands upon this dyke, where the latter is found cutting an outlier of the ash-bed. At the contact of the two rocks, however, there is some fine-grained basaltic rock, which is cut by the coarser-grained material, and which no doubt represents an earlier intrusion. A section (2554) taken from the contact of the two igneous rocks shows a fairly sharp boundary between a coarse-grained dolerite and a porphyritic basalt, with an extremely fine-grained base.

This fine-grained rock has very marked resemblances to a band of basalt which appears near the top of the ash-bed on Mount Enterprise and Valetta. It is only from 5 to 15 feet in thickness, but keeps to one horizon for about 2 miles, forming a small cliff, and giving rise to cascades in the ravines. The rock is compact and columnar in habit; it is not vesicular along its upper surface, and has baked the ash along the upper contact, and is therefore an intrusive sheet, and not a contemporaneous lava flow. The thin section (2555) shows phenocrysts of labradorite felspar and of augite set in an excessively fine-grained groundmass, which under a high magnification is found to consist of granules and prisms of augite, with granules of iron-ore set in a colourless base, which is probably in great part felspar. The specific gravity is 2.92, which brings it to the border line of the class of the Karroo dolerites.

The dolerite mass on Mount Enterprise is dyke-like in character and cut through the ash nearly vertically, swelling out at several points and forming conical hills; the rock is moderately fine-grained, and much of it is amygdaloidal. This intrusion may possible represent the source of some of the Drakensberg basalts.

To the south it ends abruptly in the Cave sandstone, but about half a mile further in that direction (on the farm Monzie) there is a lofty conical hill, formed by a plug of dolerite, which cuts both the Cave sandstone and the ash-bed. The sandstones at the contact are much brecciated, passing into

a rock which was taken to be a volcanic breccia. On the north side the ash-bed dips towards the plug, so that it is possible that the intrusion really fills a neck. The dolerite, which gives off a sheet that can be followed until it joins up with the network of the Karroo dolerites, is a rock with a density of 2.91. In thin section (2553) it shows good ophitic structure, though in a few places the felspar crystals form aggregates; there are small grains of olivine altered in places to serpentine. The spaces between the crystals are filled with pale brown glass, partially devitrified, and in such places being lighter in colour and full of fibres of felspar, granules of augite, and strings of magnetite crystals.

From the behaviour of these intrusions, from the vesicular structure which they frequently possess, from their density, which is usually intermediate between that of the compact basalts of the Drakensberg and that of the Karroo dolerites, it seems not unlikely that we have here the material filling fissures from which basaltic lavas were at one time erupted. This type of vulcanicity has indeed been surmised to have been present and to have been of some importance in Matatiele.[1] Although the large number of volcanic necks would at first sight appear to make it unnecessary to look for any other channels from which the lavas may have issued, it is remarkable to find that by far the larger number of these pipes are filled not with plugs of igneous rocks or with basic agglomerates, but with siliceous breccias and sandstone-like materials. These siliceous tuffs do not appear to mark a late stage in the eruptions, otherwise there would be tuffs of corresponding nature high up among the basalts, which is not the case. From such necks, therefore, basaltic lavas could hardly have issued, and it is not improbable that fissure eruptions played a far more important part in the building up of the Drakensberg than has hitherto been believed.

## THE VOLCANIC BEDS.

The basaltic lavas building up the upper portions of the Drakensberg lie very nearly horizontally, though there is a very gentle falling of the base of this formation from 7,000 feet above sea-level in the south of the district to 6,000 in the north. The thickness of volcanic beds is therefore considerable, and exceeds 3,000 feet along the northern half of the range. An almost insignificant proportion is composed of intercalations of sediment, principally cream-coloured sandstone, identical as a rule in character with the Cave sandstone; these, however, are of great importance on account of the evidence which they furnish regarding the geological history of the eruptions.

---

[1]Annual Report for 1902, pp. 48-50.

Such a band appears on Rush Valley, Thoresway and Antelope Park, about 400 above the base of the volcanics. On the last named farm it is about 15 feet thick, and from yellow to pinkish in colour, with one or two ashy bands and also some shale. It can be followed round to Eland Heights, where there are good exposures, and at one point the rock becomes a white, intensely hard quartzite, the sandstone having been locally indurated, possibly by heated waters charged with silica. The stratum can be traced northwards over Templer Horne, and on the hillside south of the homestead of Swithland, where, however, it is thin. By this time the thickness of volcanics has increased to 800 feet, and a second bed of sandstone has made its appearance nearly in the middle of these underlying lavas.

This stratum appears first on the boundary of Mount Fletcher, and seems to cover a wide area on the farm Risler, where it forms the bottom of a shallow valley, and with outcrops few and far between. It can be followed round the spurs of the plateau on Bosworth, Ulverscroft and Bradgate, thinning out towards the west. Thus on Ulverscroft it is a narrow band of hard sandstone, while at the drift of the main road on Swithland it is only 3 feet thick, including a shaly layer. On Bradgate it has swelled to 75 feet, but disappears on the adjoining farm Bowden, though a thin band is seen in the same horizon—about 300 feet above the Cave sandstone—on Scraptoft, and again in the valley north of Mcamballala.

At the Tent Kop in Maclear there is the following section from above downwards, best exposed on the north face of this conical hill:

| | |
|---|---|
| Tough, coarsely crystalline basalt, very jointed, but decomposed and crumbly at base ... ... ... ... ... | 140 feet |
| Pale blue mudstone and ash with occasional blocks of basalt and passing through yellow sandstone into ... ... ... ... ... ... ... ... ... ... ... ... ... ... | 50 feet |
| Pinkish and purplish-blue ash, coarse in places ... | 55 feet |
| Compact dark basalts ... ... ... ... ... ... ... ... ... ... ... | 165 feet |
| Cave sandstone ... ... ... ... ... ... ... ... ... ... ... ... ... | 240 feet |

As a rule the volcanics rest with apparent conformity upon either the ash-bed or the Cave sandstone. On the ridge separating the farm Linton in Mount Fletcher from the Tokwana Valley there is a distinct unconformity. The Cave sandstone is affected by gentle dips, but the base of the lavas descends or acsends more rapidly than the dips of the sandstone; the volcanics therefore occupy trough-shaped hollows in the underlying formation which trend nearly north and south. The sandstone is indurated and stained reddish at the contact while in places it has been rendered appreciably prismatic to a depth of several feet. The lavas are however

amygdaloidal, and there is a slight development of pipe-amygdaloid at the base. Probably these represent troughs eroded out of the sandstone along which the lavas flowed.

The basalts consist of alternations of tough and massive coarsely crystalline rock with easier weathering vesicular varieties; it is on account of these alternating harder and softer bands that the Drakensberg possesses a rudely terraced character. The basalts are often much weathered and the more vesicular varieties are seldom well seen even along road cuttings, so that the only spots at which fairly fresh specimens of the latter can be obtained are along stream beds as a rule.

As regards the thickness of individual flows some, well seen along the road cuttings between Tent Kop and Mcamballala, are from 10 to 15 feet in thickness, but the more massive beds are frequently from 50 to over 100 feet without showing any change lithologically. At the very base of the series round about Tsitsana there is a very coarsely crystalline flow which appears to be from 300 to over 400 feet in thickness, while again at several points along the summit of the Drakensberg cliffs are produced by flows which seem to be of about similar magnitude. The junction of two flows forms usually a somewhat undulating line, but its maximum inclination never exceeds about 15° and then only for a couple of yards. In a number of places there are thin layers of blue-grey flinty material somewhat like chert, which appear to be patches of sediment baked between two lava flows. No doubt the percolation of heated waters has indurated these deposits. Pipe-amygdales are common at the base of some of the flows, more especially the vesicular varieties. At Mooi River Head such pipes were found at various horizons up to 1,000 feet above the base of the volcanics at least; many of the pipes were much inclined with a dip towards the north indicating a flow of the lava in the opposite direction.

A very interesing discovery too was the occurrence of the peculiar rows of vesicles passing vertically through the lava such as were first recorded from the volcanic rocks of the Ventersdorp system under the name of "vesicle-cylinders."[1]

At Mooi River Head these structures were found in places to exceed 6 inches in diameter, but elsewhere they are usually from 1 to 3 inches. In each case the vertical vesicle-cylinders are found in compact basalt at form 3 to 6 feet above the base of the flow which commonly possesses "pipes" rising from its lower surface.

Complete longitudinal sections are seldom seen on account of the nature of the structures, but many examples exceed two feet in visible length; in some of the smaller ones the vesicles have coalesced to form a single long "pipe."

---

[1] Geological Magazine, p. 13, 1907.

The probable mode of origin of these structures has been described in the article referred to, but as confirmation of the view put forward, there it may be stated that the cylinders occurred near the base of the flows, the sheet resting in one case on an earlier extrusion, and in a second upon a band of sandstone and shale a few inches in thickness.

*Petrology of the Lavas.*—To the full accounts given in the Reports for 1902 and 1904 there is not very much to add. With one exception all the rocks collected were basalts, some containing olivine, others without that mineral. The exception was an extremely pumicious lava pale in colour with numerous steam holes lined with small quartz crystals filled with chalcedony.

The thin section (2578) shows under the microscope characters which place it among the acid lavas, in the group of the rhyolites and quartz-felsites in fact. Quartz is abundant, in well rounded blebs for the most part, though less frequently exhibiting sub-angular outlines; the grains are full of lines of bubbles and rows of minute inclusions. The groundmass consists of felspar full of fine dusty matter, small patches of iron ores or of chlorite, granules of epidote, etc., and is therefore of a brownish colour. No repeated twinning was noticed in the felspar and the latter may therefore be orthoclase. There may be some colourless or pale brownish glass present, and in places there is a spherulitic structure though not very marked; probably the groundmass has become partially devitrified. Ferro-magnesian minerals are represented by aggregates of yellow chlorite and there are a few grains of zircon. The rock is therefore a quartz-felsite or a rhyolite (including in that term lavas not showing the usual glassy base and fluxion structure) and is in consequence of great interest as being the first recorded example of such an acid type in the Drakensberg beds in the Cape Province, though such lavas are extremely well represented in the Lebombo Range in Zululand and further north along the eastern border of the Transvaal, where they appear in great force overlying basalts that have been correlated with those of the Stormberg series.

The basalts in this section of the Drakensberg exhibit a greater tendency towards ophitic intergrowth of angite and felspar than has been noticed in either Elliot or Barkly East. A section (2572) from the north side of Falstaff Glen, Maclear, is a fine ophitic basalt extremely rich in olivine, the latter mineral being found in large nearly idiomorphic crystals partially altered to serpentine; brown dusty glass fills the spaces between the constituent minerals. A curious basalt comes from Antelope Park, Maclear. The slide (2574) shows a fine grained rock with numerous laths of slightly altered plagioclase felspar and small areas of apparently altered

angite. Under a high power the latter is found to be quite fresh and very pale yellow in colour, but commonly crowded with crystals of iron ore from fairly large individuals down to excessively minute particles. The vesicles too are peculiar in containing a basalt of slightly different composition to that of the bulk of the rock, and within these spaces there are amygdales which have been filled with zeolite. It seems as though during the cooling of the rock a residual portion of the lava had oozed out of the nearly solidified basalt into the steam cavities and had there congealed.[1] The material consists of more or less skeletal crystals of plagioclase felspar and long crystals of yellow augite similar to that in the rest of the slide, but practically free of iron ores, while the groundmass is composed of an unstriated and more acid felspar full of microlites, iron ores and dusty matter, the former being sometimes arranged in tufts and radiating masses.

## THE KARROO DOLERITES.

Intrusions of dolerite are present in abundance in the form of sheets and dykes.

*Sheets* are characteristic as a rule of the lower section of the Molteno Beds following more or less closely the horizon immedaitely above the Indwe sandstone and that of the Gubenxa coal. Such almost horizontal intrusions are conspicuous therefore in the Umga Field-cornetcy and along the Maclear-Tsolo boundary, but are most prominent in the high ground overlooking the Bashee River where the dolerite forms precipices and is commonly columnar, the vertical prisms having not infrequently a height of 150 feet.

Inclined sheets accompany the horizontal injections but are more numerous in the high ground nearer the Drakensberg composed mainly of Red Beds, where they generally occur to the exclusion of the flat-lying intrusions. A small amount of faulting has occasionally accompanied the penetration of the strata, the fault faces being separated by the width of the invading dolerite. Occasionally an irregular, more or less plug-like, mass of dolerite is found, as for example in the hill on which the beacon called Leverrier is situated, not far from Inxu Siding, Maclear.

*Dykes* are ubiquitious in this area, usually narrow (from 3 to 20 feet wide) and vertical, many of them running in nearly straight lines for considerable distances, many being over 15 miles in length. These narrow intrusions are sometimes very difficult to trace for several reasons. Firstly the rock may be very decomposed and therefore give rise to no feature. In

[1] Compare Teall. The Amygdaloids of the Tynemouth Dyke Geological Magazine, p. 481, 1889.

this connection attention must be drawn to the extremely weathered nature of a few of the dykes, for example on Waai Nek and Hillside, Maclear, where the dolerite is represented by a yellow or orange-red earth, very like a mudstone, in which cores of rotten but recognizable igneous rock are still to be found.

Secondly the ground is often so grass covered, especially along shallow valleys, that there may be no outcrops. The most satisfactory method of tracing these intrusions is to notice the breaks made in the scarps of the sandstone terraces where they are cut by dykes, for the dolerite commonly weathers faster than the sandstone, producing a distinct "pathway" or "nick."

As regards the direction of these dykes, it is found that the majority can be placed in one or other of two groups striking either between N.N.E. and N. or between W.N.W. and W., and therefore crossing approximately at right angles; there are also several prominent dykes having a north-westerly bearing. The relationship of these dykes to the sheets is not everywhere the same. In some instances sheets terminate against dykes and the latter can be proved to have formed feeders from which the molten rock spread out between layers of the horizontal strata. In others, the dykes cut through the sheets and are therefore later in age than the latter; this is not unusually the case in this area.

As regards the petrological character of the dolerites there is little to add to the accounts of these rocks from other parts of Cape Colony. The thickest intrusions are coarse dolerites with plagioclase felspar prisms enclosed ophitically in the augite crystals, while olivine may either be present or absent. In some of the lesser dykes the ophitic structure is not well developed and the augite has a granular habit.

In a few cases amygdaloidal structures have been observed in dolerites which are clearly intrusive in the strata and remote from the volcanics of the Drakensberg, and which consequently cannot be considered as immediate feeders belonging to the latter.

In one instance an inclined sheet, at a point a little to the east of Engcobo road and about one and a half miles south-east of Dalasili pile, exhibited almost at its junction with mudstones small vesicles filled in with amethystine quartz. A second is finely exposed in the road cutting a few miles north-west of N'Tabodule store (Qumbu). In the centre of the dolerite sheet there are rows of little vesicles arranged in bands a few inches distant from one another; these bands run horizontally, but where the top of the sheet rises the rows of vesicles rise as well, maintaining their distance from the margin. The hollows are filled either with a blackish substance like saponite or with a zeolite.

The strata are often metamorphosed at the contacts with intrusions, but the only case worthy of record is the conversion of coarse-grained Molteno sandstone into extremely hard whitish quartzite. This is seen just above the road to Tent Kop at a point where it crosses a small stream about one mile out of Maclear town.

## SURFACE QUARTZITE.

Very interesting is the discovery of a patch of surface quartzite close to Mount Frere, on the main road about a quarter of a mile south of the trig-station, Red Hill, the underlying rock being dolerite. The exposures are poor, but one big block is seen and a number of smaller ones; probably the entire area composed of this rock is not more than 250 feet across.

The material is fine grained, yellow-brown in colour and banded in places; some parts are soft, others are much indurated and with small cavities lined by opaline silica. The occasionally ochreous nature of the rock links it with the ferruginous surface deposits or ironstones, a small patch of which is seen along the main road a few miles towards the south-west. This small area of surface quartzite occurring as it does at a height of 4220 feet above sea-level is of great interest, for no other exposures of this rock have as yet been observed in the Transkei except the isolated patch forming the summit of Kentani Hill in the extreme south-west.[1]

[1] Annual Report Geological Commission for 1901, p. 66.

# GEOLOGICAL SURVEY

OF THE

# COPPER-NICKEL DEPOSITS

OF THE

# INSIZWA, MOUNT AYLIFF, EAST GRIQUALAND,

BY

ALEX. L. DU TOIT.

# REPORT

ON THE

# COPPER-NICKEL DEPOSITS

OF THE

# INSIZWA, MOUNT AYLIFF, EAST GRIQUALAND,

BY

ALEX L. DU TOIT.

---

It is a full score of years since the discovery of copper ore in the Insizwa Range, Mount Ayliff, was made known, but it is only in the last half decade that systematic prospecting of the occurrences has been carried out. The stimulus was afforded by the discovery of nickel in association with the copper, while further impetus was given to prospecting through the discovery by Mr. J. G. Rose, F.C.S., of platinum in the ore, though in variable amount. The development of this area has experienced the usual set-backs caused, firstly by lack of capital, most of the funds having been raised locally, and secondly by the fact that much of the earlier work was misdirected owing to the unusual habit of the occurrence and insufficient knowledge of the character of the deposit.

Although time did not allow of a complete exploration of the district and more particularly of the area lying west of the Umzimvubu River, the whole of the region in which prospecting operations had been carried out was examined and geologically surveyed. For this purpose a plane-table survey was made on the scale of 600 Cape roods (about three-quarters of a mile) to an inch, the basis being the beacons of the Secondary Triangulation of East Griqualand only recently carried out.

*Topography.*—The block of ground is traversed from north to south by the two rivers the Umzimvubu (St. John's) and the Umzimhlava, the altitudes of the respective bridges along the main road to Kokstad being just under 3,000 feet above sea-level. Between the rivers there rises the great mass of the Insizwa to a height of over 6,000 feet above sea-level, the base of which is roughly defined by the row of prospecting areas indicated on the accompanying map. The Insizwa shows a precipitous face on south-west, south and south-east, but a number of narrow kloofs lead into the mountain mass, the principal of which are the Ndakeni and the Mkokweni

on the west and the Sirogobeni Stream on the east. The watershed runs northwards from the Insizwa (6129 feet) culminating in the point Cinikungu (6129 feet) close to the Mount Currie boundary along which the high ground breaks off. The mountain mass throws off two arms, one in a west-north-westerly direction towards Cedarville and the other in an east-north-easterly direction to the Natal Border. Through the former the Umzimvubu has cut a deep winding course forming very rugged country. Through the latter at a low point in the range the Umzimhlava has cut a crooked gorge, to both north and south of which the country becomes fairly open. The main road from Mount Ayliff to Kokstad has been carried over another low part along this ridge at Brook's Nek (5200 feet), leaving the towering mass of Nolangeni (6610 feet) to the south-west. Along the Natal Border the range culminates in the lofty Ingeli Mountain (7,442 feet) overlooking the low-lying territory of the Alfred Country. The eastern boundary of the area is formed by the Embongweni Hills rising in the south to form the mass of high ground on which the beacon Tonti (5710 feet) is located immediately behind the town of Mount Ayliff (3450 feet).

Since the country possesses a high rainfall, it is very well watered with abundance of soil and grass, and it has patches of forest here and there under or in the mountains and thorn-trees along the river banks. With the exception of Mount Currie, which is cut up into farms occupied by Europeans, the district is entirely Native Territory.

*Geology.*—The strata are bluish shales, flagstones and thin sandstones belonging to the Beaufort series of the Karroo System and lying nearly horizontally. These beds have been penetrated by numerous intrusions of igneous rock belonging to the Karroo dolerites in the form of sheets and dykes.

Most of this rock can be called dolerite, but the great sheet of the Insizwa Range and of the adjoining peaks and ridges is composed of a much coarser and more basic variety which can be called gabbro, of which indeed there are several distinct types, principally olivine-gabbro and olivine-norite, merging one into the other and into the dolerites. The metamorphism of the strata by the igneous rock has been intense in many places, much more so than is the rule in the Karroo or Stormberg.

The copper-nickel ores are confined more or less to the contact of the gabbro and the altered sediment, impregnating the latter to a small extent, but becoming more abundant in, and sometimes restricted to, the igneous rock of which sulphides appear to be *original* constituents.

The mode of occurrence of the ores is somewhat similar to that of the copper-nickel deposits of the Sudbury area in Ontario, Canada, and of Norway, as will be pointed out later.

*Literature.*—The only literature dealing with the Insizwa deposits consists of descriptions of the ores and the results of the analyses of the same by Mr. J. G. Rose, F.C.S., embodied in the Reports of the Senior Analyst for 1908 and 1909, Cape Town, and a good, though brief, account of the occurrence by the same writer in the South African Science Journal (S.A. Ass. Adv. Sci.) Vol. vii. Jan. 1911 p. 129-131, Cape Town.

## THE BEAUFORT BEDS.

As a rule the depth of soil is commonly sufficient to hide the strata, and the latter are only well exposed along the rivers and in the gorges or along road cuttings. Towards the base of the mountains there are also in many places great quantities of fallen debris which hide the underlying formation, as for example behind the town of Mount Ayliff. Beneath such accumulations of talus, charged with moisture for the greater part of the year, the rocks rapidly decompose and the sandstones and shales, even where converted into tough hornfels, are frequently weathered into cream, pink or red clays covered by deep red soil.

The strata consist of pale greenish or bluish sandstones, weathering yellowish and brownish in colour, with a good deal of arenaceous blue-green mudstones and flaggy beds with very little true shale. The harder and softer beds alternate closely and only now and then give rise to terrace-like features on the hillsides. Many of the beds contain a small amount of carbonate of lime, sometimes giving thin calcareous sandstones and flagstones and sometimes collected together in the form of calcareous nodules or concretions.

All the strata, even those along the crest-line of the Insizwa, have a prevailing green or bluish tint; in this respect the beds differ from those which occur around Qumbu and Mount Frere in which purple-coloured rocks play an important part. A few thin purple bands were observed at a few points, namely, between Ndakeni and Rode stores, at the bend in the road descending the Red Hill east of Sugarbush, and below the area belonging to the Mount Ayliff Developing Syndicate, but being only a few feet in thickness they are of no importance. The strata in Mount Ayliff differ in character again from the beds provisionally correlated with the Ecca which are found further to the east at Umsikaba and Bizana[1] for instance, and which are lower down in the geological sequence.

For these reasons the strata in this area are tentatively correlated with the Middle and possibly also with the Lower Beaufort Beds of the Karroo, though further work will have to be done to prove their exact horizon.

[1]Annual Report Geological Commission for 1901, pp. 27-30.

Fossil remains are extremely rare in them. A small reptilian bone was obtained at Mount Ayliff, while good examples of *Glossopteris* were discovered not far from Dundee store and again in a quarry at the southern corner of the town of Kokstad close to the bridge over the Umzimhlava River. Fragments of fluted stems, probably a species of *Schizoneura*, are not uncommon at various points, as for example at Mount Ayliff where a few leaf-whorls were also obtained belonging to *Phyllotheca*.

The metamorphism which these beds have experienced will be described later on.

## The Dolerites, Gabbros and Norites.

As can be seen from the map the strata are penetrated by numerous intrusions of igneous rock in the form of a network of sheets accompanied by a limited number of vertical dykes. The sheet building up the Insizwa—Nolangeni—Ingeli mass and that composing Tonti differ from most of the remaining intrusions petrologically, while the former is, at least in the south, nearly independent of, and detached from, the sheets and dykes which penetrate the strata around its base. For this reason the Insizwa gabbro will be considered separately, though, as will be pointed out later, the igneous rocks of the area all form a single network so that one petrological type can be easily traced in the field and found to pass gradually into another. In only a few places were later intrusions found marking a slightly younger eruptive phase; these were in the form of narrow vertical dykes cutting the sheets of the area, a feature, however, which has been observed both in Stormberg and in the Central Karroo and is therefore not peculiar to this region.

Between the Umzimvubu Bridge and the Insizwa there are several important sheets with a gentle inclination to the south. One of these following closely the course of the River passes Ndakeni store, where shafts have proved ores at the contract with shales, and the intrusion continues below the talus slopes of the range and probably joins up with the Insizwa sheet just below the Trig. Station Ndakeni (5,898 feet). An offshoot strikes north-westwards and joins the main mass on the south bank of the River a few miles further on. The inclined sheet which follows the main road for three miles just east of Rode Hotel is of interest as being obviously a feeder to the Insizwa mass, dipping as it does towards the south and forming the ground on which the Trig. Station Lucwezo stands; it is probably the same intrusion as that forming the elevation known as Red Hill a little further to the east. In the short distance between Rode and Sugarbush it changes its lithological character from a typical coarse ophitic olivine dolerite to a lighter coloured and coarser gabbro identical with that forming the range a mile to the north.

On the south-eastern side of the range there is only one point where any feeder of importance actually joins up with the Insizwa mass, and this is found at the north-eastern extremity of the Insizwa Mining area.

This is formed by a broad dyke of gabbro (accompanied by a nearly horizontal offshoot) which strikes eastwards, crosses the Umzimhlava River, dipping at a high angle to the south, and forms a prominent little hill overlooking the town of Mount Ayliff. Here it makes an abrupt bend through a right angle and strikes northwards. Small amounts of copper ores are stated to have been found along this intrusion.

Between Mount Ayliff and Brook's Nek there are a number of sheets inclined at a gentle angle to the south-east or east, sometimes uniting and then breaking up again, producing belts with more or less parallel outcrops. The lower and lesser sheets appear on the undulating ground along and to the west of the main road, while the upper intrusions build up the Embongweni Hills; the former join with the huge mass of Nolangeni, while the latter ramify in a complex manner and ultimately merge in the range of the Ingeli with its great precipice of rudely columnar rock overlooking the headwaters of the Umtamvuna River.

Around Brook's Nek Hotel, where the geological structure is clearly revealed in the numerous ravines, the sheets of dolerite and gabbro are found to undulate, forming pseudo-anticlines and synclines as in the Glen Grey district. The section across Brook's Nek, over which the main road crosses at the height of 5200 feet above sea-level, shows that the north-eastern arm of the Insizwa mass is almost certainly a huge dyke which spreads as it rises and gives off on either side several flatter and diverging sheets (Fig. 1 A.)

A similar structure is found in the Nolangeni mass, which is of interest too on account of the narrow strip of much metamorphosed strata included in the mass of igneous rock which is here roughly fan-shaped in vertical section (Fig. 1 B.)

Within the district of Mount Currie this inward dip of the junction of the two formations is very well seen, the boundary striking westwards across the Umzimhlava, and the thickness of the intrusion where cut through by the river must be very considerable, for the contact usually dips at from 20° to 30°. Beyond the deep and narrow gorge of the Umzimhlava the sheet spreads out to form a roughly oval area a little over 10 miles across bounded by cliffs often showing a rudely columnar structure. Round its periphery the sheet dips inwards and passes below a considerable area of sediments which thus lie in the interior of a basin-shaped mass of igneous rock and which are pierced in places by sheets and dykes,

offshoots of the underlying intrusion (Fig. 2). The igneous rock at the upper contact is frequently columnar. The habit of the intrusion recalls at once the peculiar "basin-shaped" or "annular" sheets which are so characteristic of Glen Grey and Queenstown[1] and the mode of occurrence is quite dissimilar to that of the Sudbury Area in Canada. In the latter the "basin-like" structure has apparently originated through subsidence which has taken place below what is now the centre of the basin; in the former the strata remain absolutely

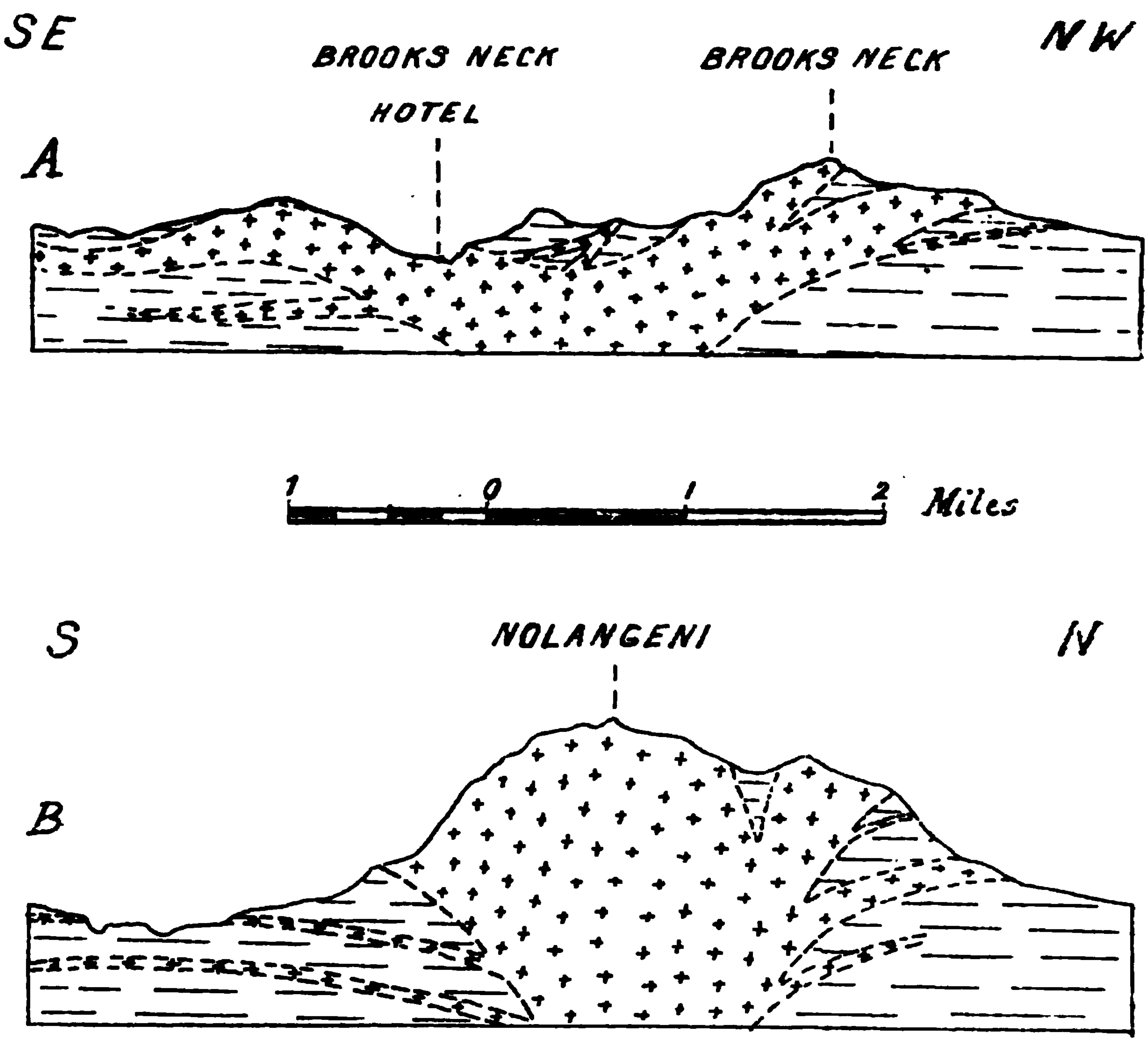



FIG. 1—Sections through the Insizwa intrusion over Brooks Neck and Nolangeni Mountain respectively.

undisturbed and almost horizontal, while the igneous material has made its way along a regularly-curved surface of fracture to form an evenly curved or "basin-like" sheet (Fig. 2). On both east and west the inward dip is lower than on the south and south-east but the breadth of outcrop is less in the latter direction. The thickness of the sheet is probably therefore fairly uniform with a value ranging between 2,000 and 3,000 feet. This is much greater than any of the hitherto known

[1]Annual Report Geological Commission for 1905, pp. 134-6.

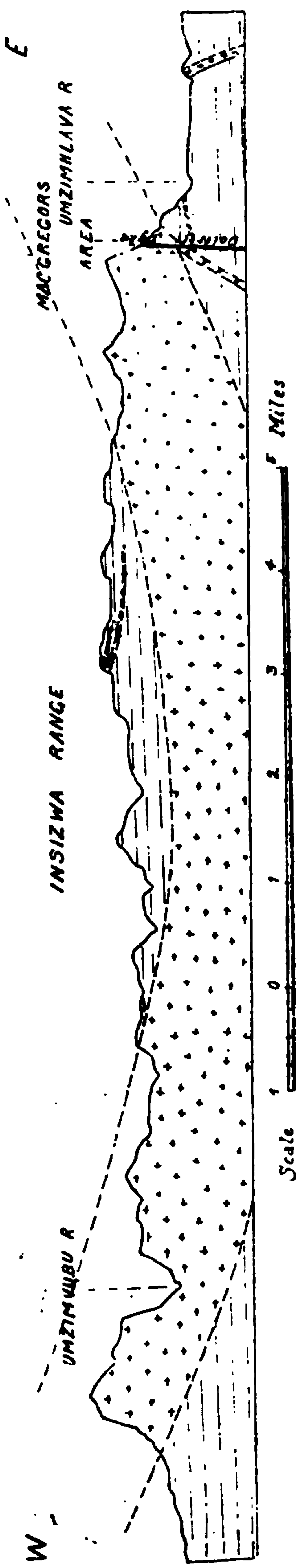



FIG. 2.—Section across the Insizwa Range from west to east, showing the basin-shape of the gabbro-norite sheet; vertical scale about two and a half times horizontal.

sheets of Karroo dolerite though approached closely in some of the great curved sheets of Queenstown, for example the Andriesberg and the Wildschuts Berg. Nowhere does the intrusive mass of the Insizwa show any tendency to a laccolitic habit, and the strata forming the "roof" are only tilted at one point, and then by an inclined sill of dolerite. The view hitherto held, that the Insizwa mass is of the nature of a laccolite, fails to receive any support in the field whetever.

All along the line of the mining areas the base of the gabbro dips inwards at from 20° to 30° in a very regular manner. On MacGregor's Area, however, the dip has increased to 40° in places, but this value apparently is not the true dip of the main sheet, for the following reasons. The section at about the middle of the area shows the contact dipping at 40°, with the basal part of the gabbro decomposed to a friable material; above this rotten portion there comes a markedly harder zone, which can be followed along the hillside with a dip of only 10°—12°, surmounted hy rough-weathering cliffs. This feature is also apparent several miles to the south, and makes it probable that the eastern contact for some distance at least is formed by a sill or feeder. As a matter of fact, at the northern extremity of MacGregor's Area this feeder, which is of no great thickness, crosses the bed of the Kange stream, while the base of the main sheet, which is lying at a much lower angle, extends for about one-third of a mile up the valley, rejoining the small sill on Hornby's Area.

The actual contact of the gabbro with the altered shales is rarely exposed naturally; indeed, along the greater part of the line of mining leases the junction, which is usually some distance up the mountain side, is hidden below an abundant talus and by soil and grass, while just east of the Umzimhlava Poort there is a large area of flat ground covered with deep soil and mostly under cultivation; for this reason prospecting is a difficult task. Fortunately, the induration which the shales have experienced causes them to make outcrops and to produce sometimes a marked feature, so that the base of the sheet has been struck with considerable precision over the various areas.

### The Character of the Insizwa Ores.

Owing to the infrequent exposures of the base of the gabbro the presence or absence of ore is, as a rule, only proved by actual sinking and driving. In most instances prospecting pits have been sunk wherever the rocks were found stained with the green carbonate of copper (*malachite*)—probably also the silicate of nickel (*garnierite*)—produced by the weathering of sulphides, and usually accompanied by a good deal of hydrated oxide of iron, *limonite*. Practically three minerals make up the ore patches or bodies, two of which are always distinguishable by the eye in hand specimens. The most abundant mineral is *pyrrhotite*, a sulphide of iron of slightly variable composition, but containing about 61 per cent. of metallic iron on the average. It is recognisable by its bronzy metallic lustre, and somewhat platy structure, and by the fact that it is feebly magnetic and attracts the compass needle.

The second ore is *chalcopyrite*, or copper pyrite, sulphide of copper and iron, which is easily identified by its brassy appearance and soft nature; it contains a good deal of iron, and the copper percentage is about 34.5. The third important mineral is *pentlandite*, a sulphide of nickel and iron, with variable composition, but containing on an average about 20 to 35 per cent. of nickel. Having also a bronzy colour, it cannot be identified in the hand specimen, but was proved to be present after treating polished pieces of the ore-bearing rock with acid, as will be mentioned later on in dealing with the genesis of the ores.

The ores can be roughly grouped into two classes, one rich in chalcopyrite and therefore in copper, but with a low amount of nickel, and the other rich in pyrrhotite and pentlandite, and therefore having a larger proportion of nickel. This, which was first pointed out in the Report of the Senior Analyst,[1] is borne out by observations in the field. It is improbable, however, that any advantage can be taken of this rough classification after mining, firstly because the ore varies so rapidly in

[1] Report for the year 1908, p. 118.

character from point to point, and secondly because the admixture of the minerals is so intimate a one, as shown in thin sections of the ore, as to make it improbable that the nickel-bearing pyrrhotite can be separated mechanically from the chalcopyrite.

In addition to these three important minerals, a small quantity of *bornite* (sulphide of copper and iron) was obtained from No. 3 adit, Insizwa, in the form of thin layers along joints in highly altered sandstone close to the contact.

*Niccolite*, the arsenide of nickel, containing 43 per cent. of that metal, was observed in very thin veins in the much altered foot-wall from the adit of the A. Payne Syndicate. I was informed by Mr. Brennan that this is the only locality at which this mineral has been noticed.

In what form the platinum exists in the ore is not yet known, but from the resemblance to the Sudbury deposits and from the existence here of arsenides, it is not unlikely that it is present in the form of *sperrylite*. Platinum was also found by Mr. Rose to be present in a sample of iron ore (ilmenite) which I collected on the eastern slope of the Insizwa after a heavy rain, the deposit occurring as occasional thin washes upon the soil derived from the weathered gabbro of the mountain.

*The Ore Values.*—Assays were made by Mr. J. G. Rose, in the Analytical Laboratory, Cape Town, of material collected by him, and the following is a summary[1] of the values on material obtained from the adits of the Insizwa Mining Area:

| | |
|---|---|
| | Per cent. |
| Highest copper content ... ... ... ... ... | 19.3 |
| Lowest copper content... ... ... ... ... | 1.2 |
| Average of 14 analyses ... ... ... ... ... | 4.1 |
| Highest nickel content... ... ... ... ... | 7.3 |
| Lowest ... ... ... ... ... ... ... ... ... ... | 0.6 |
| Average of 14 analyses ... ... ... ... ... | 3.8 |
| | Per ton of 2,000 lbs. |
| Highest Platinum content ... ... ... ... | 4 oz. 19 dwts. |
| Lowest ,, ,, ... ... ... ... ... | 12 grains |
| Average of 14 assays ... ... ... ... | 2 dwts. 15 grains |

Cobalt, silver, gold and osmiridium occur in traces.

Two trial shipments of some five tons each sent to England soon after the author's visit, were analysed by Messrs. Johnson, Matthey and Co., with the following results:—

| | | |
|---|---|---|
| | Per cent. 1. | Per cent. 2. |
| Copper... ... ... ... ... ... ... | 3.40 | 3.50 |
| Nickel and Cobalt ... ... ... | 4.90 | 5.25 |
| | Per ton. | Per ton. |
| Gold ... ... ... ... ... ... ... ... | 6 grains | 6 grains |
| Platinum, 2 dwts 12 grains per ton | | 12 grains |
| Silver ... ... ... ... ... ...... | 10 dwts. | 12 dwts. |

[1]The South African Journal of Science, vol. vii., p. 130, 1911.

## THE LOWER CONTACT OF THE GABBRO.

Owing to the usually concealed lower junction, the study of the relation of the intrusion to the sediments and the nature of the contact, etc., is more or less confined to the adits and shafts along the line of mining areas.

The junction is well seen along the Nolangeni Mining Area, towards the south-western base of the mountain of that name. Here the strata, baked through a considerable thickness into intensely hard hornfels, form a prominent ridge extending down to the Umzimhlava River. The gabbro underlies the lower ground at the foot of this ridge, but the boundary rises to the east, and is seen in a small ravine, a stream having cut its channel along the junction of the two rocks.

The hornfels is horizontal, except just near the contact, where there has been a downward drag of the strata, amounting in places to 10° or 15°, but for about 50 feet or so only. The base of the gabbro is somewhat uneven, and here and there tongues have been pushed into the hornfels; taken as a whole, however, the contact is very regular, and dips to the north at from 20° to 25°. The gabbro is quite coarse in texture right up to the contact; in some places the rock is quite fresh and solid; in others it is decomposed and friable.

The hornfels just below the contact is full of little veins and stringers of granite or quartz-diorite, mostly vertical, and now and then running to several inches in width. The boundaries of this white granitic material are ill-defined in the hornfels, fading away in the body of the latter, and showing that the igneous matter penetrated into cracks and diffused from them into the country rock. Pale patches, characterised by abundant felspar, are common close to the contact, and the hornfels is in places so impregnated with igneous matter and so recrystallised that its sedimentary origin is at first sight unrecognisable, though bedding planes are usually apparent on partially weathered surfaces.

The basal portion of the gabbro itself is traversed by similar acid (granitic) veins running in various directions, more or less highly inclined, diverging and uniting, and varying in thickness from a fraction of an inch to over a foot. These are well seen where they have been opened up at the head to the little ravine referred to. The veins are usually well defined from the gabbro, and have in the larger ones a thin, very white felspathic selvage, and are themselves traversed by narrow acid filaments. Some of these granite or micro-granite dykes are mineralised also.

I am indebted to Mr. E. S. Campbell, Mount Ayliff, for the following information regarding the prospecting tunnels:

A level, A, about 450 feet long, has been driven in obliquely to the outcrop, so as always to follow the contact. At a point

a little higher up the stream an incline, B, 140 feet long, was put down to cut the level A, while further up the ravine a second incline, C, was driven slightly off the dip, and about 200 feet long, falling at about 1 in 4.

In these workings the mineralisation does not seem to follow the exact contact always, for in C, at two points at least, ore was found both in the gabbro at about 3 feet above the contact and in the hornfels at about the same distance below it.

Again, in the incline B the ore has been found to run in this position more or less parallel to the contact, and then to rise up at intervals to meet the latter.

On *MacGregor's Area* the gabbro is medium-grained and dark in colour in contact with extremely tough hornfels, the two rocks being firmly welded together at the junction, the latter dipping inwards at nearly 40°. Chalcopyrite and pyrrhotite are most common about the junction, but are also found in the hornfels and abundantly in patches and specks in the igneous rock.

The workings consist of an adit, a shaft, and several other lesser pits; an adit was started low down in the face of the cliff overlooking the river, but afterwards abandoned owing to the long distance which would have to be driven in the hard barren strata.

A narrow dyke of medium-grained dolerite cuts through the range at a point half a mile north of the main opening. It is of some interest, for only one other intrusion of this type has been observed cutting the gabbro, and that between Sugarbush and the Insizwa Trig Station.

On the *Payne Syndicate's Area* there is a fine-grained microgranite dyke cutting the basal portion of the gabbro vertically, and striking nearly parallel to the contact; the dyke shows bands differing in colour and texture parallel to the sides of the intrusion. This intrusion crosses the road leading into the interior of the Insizwa, and has been opened up in a couple of prospecting pits.

The main adit is 390 feet long, the strata having a very slight inward dip, which increases close to the contact; the dip of the latter is 22½°. At the junction the gabbro contains lumps of hornblende (actinolite) rock, fairly sharply defined from the surrounding rock, and looking very much like inclusions; often they are enclosed or bordered by fine-grained white micrognanitic material. In places they are mineralised, in others barren. There is a good deal of rock here formed of gabbro and hornfels mixed, and as the strata are somewhat calcareous or contain limestone nodules, lumps of calc-silicate hornfels in well-defined masses are to be observed in the intrusive mass. Ore occurs, I was informed, mostly in the footwall, with chalcopyrite predominating, but the ore is said to run higher in nickel than elsewhere, a feature which can be

ascribed to the presence of niccolite (arsenide of nickel), which is obtainable here, in addition to pentlandite.

At a point a couple of hundred yards south of the adit, a sheet of dark-coloured, coarse ophitic dolerite comes up and joins the main mass of light-coloured gabbro, with which it merges. Prospecting pits show that the tongue of shales in the angle of the junction of the intrusions is much broken, and the shale has been pulled out into strips which are much indurated with development of felspar, so that they resemble small acid veins, cutting irregularly through the basic rock. Niccolite occurs in small quantity both in the altered shale in narrow veins and disseminated in the dolerite dyke.

On the area belonging to the *Mount Ayliff Developing Syndicate* (Button's Area) several deep shafts have been put down through hard grey gabbro to strike the contact. There is a mingling of igneous rock and hornfels, and the former contains in patches epidote and biotite mica, and is in places rich in chalcopyrite and pyrrhotite.

The *Insizwa Mining Area.*—Copper ore was discovered more than 20 years ago in a small ravine known as the Waterfall Gorge, and work has been carried on more or less spasmodically during the past five years, for lack of capital and other reasons have prevented systematic development until recently. The ore was first opened up upon a strip of light-coloured rock, up to a few feet in widh dipping at a high angle to the south, and striking obliquely towards the contact. It may be a couple of hundred feet in length; it is surrounded by somewhat weathered gabbro, and appears to be a large mass of shale torn off by the igneous rock, tilted on edge and metamorphosed; in places it is brecciated. Part of the inclusion is a calc-silicate hornfels.

Immediately below this point a level (No. 3) has been driven into the right hand bank of the stream for a distance of about 600 feet, following the contact, but with short off-sets here and there. A sheet of nearly solid ore, chalcopyrite and pyrrhotite occurs over a considerable distance along the actual junction of the two roads, swelling out to a thickness of several feet in places. At a distance of a couple feet away from the contact the hornfels is usually almost or quite barren, but in one place a sheet of sulphides leaves the contact, runs into the footwall nearly horizontally, and then rising resumes its inclined direction. Along this offshoot the nearly vertical joints of the whitish quartzite above and below the ore-body are filled with thin sheets of the copper-iron sulphide bornite. Above the contact, however, a good deal of ore is disseminated through the dark grey gabbro.

On the opposite side of the stream an adit (No. 4) driven into the hillside has cut the gabbro at 580 feet in, the junction being even and slightly wavy, with a dip of about $22\frac{1}{2}^{\circ}$. The

hornfels of the footwall is completely crystallised and traversed by narrow veins of micro-granite, in places becoming coarser in character, and containing moderately large flakes of biotite-mica.

Here, too, the ore occurs along the contact in patches and lenticles, but the bulk of it is disseminated through the mass of the gabbro throughout a considerable distance from the junction, commonly in a fairly even manner. I must acknowledge the kind assistance which I received from Mr. G. H. Blenkinsop, Manager of the Insizwa Mine, both in the matter of information regarding the property and the acquisition of typical specimens from the workings.

The base of the intrusive rock at Insizwa exhibits on weathered surfaces a banded structure dipping inwards at from 15° to 20°, and therefore nearly parallel to the base of the eruptive mass. Above Sugarbush a similar foliation, though not pronounced, is seen, the dip being about 10° inwards.

From the Insizwa round to Ndakeni the base of the sheet is rarely visible, and prospecting pits are few in number; at the Ndakeni gorge the contact descends at an angle of 25°, and in the cliff overlooking Ndakeni store the base has risen to within a few hundred feet of the top of the escarpment. At the foot of the range at this point on the Ndakeni Mining area, there is a nearly vertical dolerite dyke, giving off a horizontal sheet, and between these two intrusions a patch of shale has been caught. A shaft and adit have been driven along the wall of the dyke, and the hornfels was found to be stained with copper carbonates and limonite, but no large ore bodies seem to be present.

An interesting feature of this portion of the range is the great bare and smooth surfaces formed by the gabbro on the ridges behind Sugarbush and the picturesque precipices below the trig station Ndakeni and along the Umzimvubu gorge.

## The Petrography of the Intrusions.

While the dolerite dykes and sheets, of such common occurrence in Mount Frere, Mount Ayliff, Kokstad, etc., are dark-coloured, moderately coarse-grained rocks, composed of plagioclase (labradorite) felspar and augite, usually associated in an ophitic manner and with or without some olivine, the material composing the Insizwa, Tonti, Ingeli, etc., is much lighter-coloured and coarser in grain. In fact, in its appearance, and especially in its mode of weathering, it closely resembles a diorite. Plagioclase felspar is abundant, thus giving the rock its light colour, while on weathered surfaces there appear knots of green ferro-magnesian minerals, usually from a tenth to half an inch across, occasionally a little larger.

These are composed principally of olivine, with subordinate amounts of augite and a colourless orthorhombie pyroxene (enstatite); but, as will be detailed below, the intrusions range from a *gabbro* devoid of olivine to a type so rich in the latter mineral and deficient in felspar as to deserve the name *picrite*.

For general purposes the rocks can be grouped in three classes, namely, *gabbros* without olivine, *olivine-gabbros*, and *olivine-enstatite gabbros*, or *olivine-norites*; some of the last mentioned approach closely in composition the rocks known as eucrites.

The *olivine* is a faintly greenish variety which only rarely shows any alteration to serpentine; it is almost always partially or wholly surrounded by a ring or shell, sometimes very narrow, of pyroxene, giving rise to what is known as "corona" structure.

The *augite* is a nearly colourless variety, but in some of the olivine-free gabbros it has a brownish tinge, and is diallagic in habit. The *enstatite*, resembling it so closely in character, is liable to be passed over unnoticed; it is sometimes intergrown with the augite. This occurrence of an orthorhombie pyroxene in intrusions belonging to the Karroo dolerites is certainly exceptional in Cape Colony, though such a mineral has been identified in intrusions cutting the Karroo strata of Natal and Zululand,[1] and enstatite has been recorded from some of the Stormberg lavas and volcanic necks.[2] The plagioclase felspar is almost always *labradorite*, usually a basic variety; in one example *bytownite* was observed (2613). There is commonly, too, a very small amount of more acid plagioclase, and in some instances a lesser quantity of quartz as well, which may give rise to *micropegmatite*. This feature is not confined to the olivine-free gabbros, such as 2621, but was discovered in the more basic olivine-norite dyke 2588. *Biotite* is almost invariably present, sometimes in fair amount.

*Iron ores* are remarkably scanty, a most important characteristic of the Insizwa intrusive. Only a small amount of it is attracted by a magnet, and the presence of titanium in the ore shows that the bulk of the black mineral is *ilmenite*.

The micro-structure of the intrusive rock varies considerably from point to point, for the relationships of the four principal constituents differ considerably, this being due to the fact that the periods of crystallisation of the several minerals have probably in great measure overlapped.

The ophitic inclusion of the felspars by the augite, so characteristic of the dolerites, is a feature that is only feebly developed here, owing no doubt to the lesser amount of pyroxene present; sometimes, indeed, the augite is included in the fel-

---

[1] G. T. Prior. Annals of the Natal Museum, vol. II., pt. 2, pp. 141–157, 1910.

[2] Annual Report Geological Commission for 1904, pp. 127, 132, 150-1.

spar (2114). The olivine, on the other hand, is moulded on and may include prisms of labradorite, a structure common in the eucrites. In slide 2613, in which olivine is abundant, this mineral exhibits good idiomorphic outlines to the felspar.

The gabbros and norites represent a more basic phase of the Karroo dolerites, as shown by the four analyses quoted below, where the percentage of silica ranges from 50.66 down to as low as 43.43. The olivine-dolerites hitherto examined have not as yet been found to possess a lower silica percentage than 49.5, as shown in the analyses given by Cohen,[1] while the average analysis runs close upon 52 per cent.

Curiously enough, the specific gravity of the gabbro averages a little less than that of the normal Karroo dolerite, and in only three cases exceeds 3.0; in the picrite-like rock it is no less than 3.23, but the high value of the Insizwa ore-bearing norite, 3.12, is in part due to the presence of metallic sulphides in the specimen.

The slides cut from samples taken at different distances from the base of the Insizwa sheet, checked by the analyses quoted below, show, with one exception, a gradual decrease in basicity from the bottom to the top, pointing to differentiation in the molten mass as a whole. It is noteworthy that the olivine-free gabbros were obtained from the upper edge of the sheet, where the rock becomes somewhat coarser in character, with a tendency to carry coarsely crystalline veins containing pegmatitic intergrowths of the minerals, and that the slides here show the development of quartz-felspar micropegmatite in the rock.

That this differentiation of the magma was carried on to a far greater degree locally is indicated by the occurrence of veins of light-coloured rock penetrating both the gabbro and the hornfels, and ranging in composition from a diorite to a microgranite rich in orthocalse felspar and quartz, and in which the percentage of silica is doubtless as high as 70 at least. The existence in the Karroo dolerites of microgranite and granophyre is well known, but the Insizwa examples are of interest on account of the presence of such acid segregations forming veins in and offshoots from a much more basic body.

1. E. Cohen. Geognostisch-petrographische Skizzen aus Süd-Afrika. Neues Jahrbud für Mineralogie, etc. Beil-Bd. v., p. 249, 1887.

# ROCK ANALYSES.

## INSIZWA GABBROS.

The following four analyses of typical samples of the Insizwa sheet were carried out in the Analytical Laboratory, Cape Town, by Mr. W. Versfeld, B.Sc.:

| | No. 1. | No. 2. | No. 3. | No. 4. |
|---|---|---|---|---|
| Silica... ... ... ... ... ... ... | 48.20 | 47.74 | 50.66 | 43.43 |
| Titanium dioxide... ... ... | 0.74 | 0.25 | 0.33 | 0.07 |
| Alumina ... ... ... ... ... ... | 8.09 | 5.03 | 4.42 | 14.71 |
| Ferric oxide... ... ... ... | 5.32 | 5.24 | 6.85 | 2.23 |
| Ferrous oxide ... ... ... | 12.53 | 10.58 | 6.84 | 12.45 |
| Lime ... ... ... ... ... ... ... | 17.20 | 11.12 | 3.30 | 17.65 |
| Magnesia ... ... ... ... ... | 5.92 | 19.42 | 25.77 | 7.88 |
| Potash ... ... ... ... ... ... | 0.31 | — | 0.35 | 0.08 |
| Soda ... ... ... ... ... ... ... | 1.35 | 0.21 | 1.15 | 0.10 |
| Sulphar ... ... ... ... ... | 0.03 | 0.17 | trace | — |
| Phosphorus pentoxide | 0.14 | 0.08 | 0.06 | 0.02 |
| Copper ... ... ... ... ... ... ... | — | 0.06 | — | — |
| Water (at 120°) ... ... ... | 0.25 | 0.22 | 0.12 | 0.17 |
| Water (above 120°) ... ... | 0.43 | 0.10 | 0.28 | 1.10 |
| Total ... ... ... | 100.51 | 100.22 | 100.13 | 99.89 |

No. 1 is a *Gabbro* without olivine (slide 2621).
No. 2 is an *Olivine—gabbro* (slide (2613)
No. 3 is an *Olivine-gabbro* with *enstatite* or.
*Olivine-norite* (slide 2585).
No. 4 is an *Augite-picrite* (slide (2600).

The petrological characters of these specimens are given below in the description of the material collected from the Insizwa intrusions.

Slide 2583, *Gabbro*. From half-way up side of range. Sugarbush; a medium-grained grey rock, sp. gr. 3.00. The felspar is a basic labradorite in large prisms, practically free of inclusions, and with a strong tendency to idiomorphism. Augite in almost equal amount forms irregular plates moulded on the felspar. It is diallagic in character, being full of excessively minute inclusions of iron ore arranged in planes parallel to the brachypinacoids. There is a small amount of more acid and zoned plagioclase felspar filling spaces between the other minerals and therefore irregular, like the scanty iron ores and biotite.

Slide 2621, *Gabbro*. Top of sheet, Ndakeni Gorge; material of analysis 1. A medium-grained grey rock, with

sp. gr. 2.96. Labradorite felspar and diallagic augite are present in nearly equal proportions, producing a rock very similar to 2583, though idiomorphism is not so well developed in the felspar. The augite is commonly elongated, and shows twinning and elaborate intergrowths as well, and may contain small inclusions of iron ores. There may also be a little enstatite. Biotite is present in small amount, also a small quantity of apatite. There is a fair amount of orthoclase felspar filling more or less triangularly-shaped spaces between the plagioclase prisms, and commonly intergrown with a lesser amount of quartz to form micropegmatite.

Slide 2613, *Olivine-gabbro.* A barren portion of the ore-bearing sheet, No. 3 adit, Insizwa Mining Area; material of analysis 2. A rather dark-coloured, medium-grained rock with sp. gr. 3.12. The olivine is very fresh, and is only slightly serpentinised in a few places, very pale greenish in colour, full of small iron ores, and occasionally having abundant radiating dendrites of magnetite, very minute indeed, arranged in planes parallel to the macropinacoids. The olivine is usually bordered by augite, but where it comes into contact with the felspar it possesses crystal faces. It contains small inclusions of biotite and sometimes areas of pyroxene. The augite is irregular in outline, moulded on the felspar as a rule, and surrounding the olivine; no enstatite could be recognised. The plagioclase is idiomorphic with respect to the augite, but moulded on the olivine, while its prisms interfere with one another. It is a variety approaching bytownite in composition. There is also a more acid plagioclase in irregular patches, along with which there occurs a fair amount of biotite. Apatite is present and also metallic sulphides.

Slide 2614, *Olivine-gabbro approaching norite.* The ore-bearing rock from No. 4 Adit, Insizwa Mining Area, spangled all over with pyrrhotite and chalcopyrite (see fig 4). Olivine is abundant, often idiomorphic, and is traversed by numerous cracks and rude cleavage planes, parallel to the vertical axis. Felspar is not so abundant as in 2613, and includes numerous small patches of pyroxene. The augite occurs therefore in irregular areas, and is accompanied by a smaller amount of enstatite, with which it is sometimes intergrown. Biotite is conspicuous. The relationship of the ores, which form a fair proportion of the rocks, to the foregoing minerals will be described later on.

Slide 2593, *Olivine-gabbro.* Adit on Nolangeni Mining Area. A coarse-grained grey rock. Labradorite forms more than half of the rock as an aggregate of prisms, which mutually interfere and on which the ferromagnesian minerals are moulded. Olivine is not abundant, and is surrounded by pyroxene, the latter constituting quite a thin shell in places. The augite is slightly diallagic in habit, and is accompanied

by a small amount of enstatite, fringing either it or the olivine. Biotite is absent and iron ore is extremely scarce.

Slide 2,597. *Olivine-gabbro* approaching *Troctolite*. Below Tonti beacon, behind the town of Mount Ayliff. A coarse-grained light-coloured rock weathering with pitted and cavernous surfaces.

Labradorite felspar forms just over one-half of the bulk of the rock. Olivine is abundant in irregular granules moulded on the faces of felspar prisms and often including idiomorphic felspar. From the olivines cracks radiate outwards through the felspar in the manner typical of the troctolites. The olivine is often bordered by augite and probably also by a small amount of enstatite, but the pyroxenes are more commonly in the form of detached irregular granules located between the felspar prisms. There is a small amount of iron-ore, the grains of which are commonly attached to, or surrounded by, biotite mica.

Slide 2,611. *Olivine-gabbro*. Base of sheet, south corner of Mount Ayliff Developing Syndicate's area. A light-coloured rock with prominent areas of ferro-magnesian minerals projecting in knots from weathered surfaces; sp. gr. 2·91. About three-quarters of the bulk of the rock consists of prisms of labradorite felspar. Olivine in a perfectly fresh condition forms irregular areas moulded on the felspar, and often including the latter in a finely ophitic manner. In places it is bordered by pyroxene, but the latter, which is present in subordinate amount, is more commonly in the form of irregular or rudely triangularly-shaped areas. There is a small amount of more acid felspar and a little iron-ore associated with some biotite.

Slide 2,620. *Olivine-gabbro*. Middle of sheet Ndakeni Gorge. A light-coloured coarse-grained rock in which olivine crystals, attaining a size of a quarter of an inch across, are conspicuous; sp. gr. 2·96. The labradorite occurs in rather stout prisms accompanied by a very little interstitial felspar of much more acid composition. Olivine is abundant, showing the corona structure in regard to pyroxene and commonly moulded upon and including felspar. Augite occurs associated with the olivine, or as very irregular skeleton crystals and patches exhibiting optical continuity. Enstatite may also be present. There is a very little biotite and some apatite.

Slide 2,585. *Olivine-gabbro-norite*. Summit of Insizwa Range at Sugarbush; material of analysis 3. A dark-grey medium-grained rock; sp. gr. 2·95.

Olivine is abundant and, though sometimes including felspar, tends to idiomorphism, being enveloped by augite, which here forms rather larger areas than is usual. Into the latter prisms of felspar project and the augite is hence moulded on the plagioclase, and therefore forms polygonal areas

bounded by nearly straight lines; the mineral is feebly diallagic in character. Enstatite is present in fair quantity, but is difficult to distinguish from the augite, its behaviour towards the other constituents being so like that mineral. There is a very little acid felspar with a small amount of biotite and iron ore.

Slide 2,584. *Olivine-norite.* Half-way up the Insizwa Range behind Sugarbush. Abundant large olivines very fresh; irregular in outline owing to the felspar, which is included ophitically; partially or completely enveloped by pyroxene as a rule. The augite is distinguished from the enstatite by its slightly diallagic character, due to minute platy inclusions, but the two pyroxenes have the same habit and occur as skeleton crystals enclosing felspar ophitically or attached to the olivine. Enstatite predominates over augite and is sometimes continuous optically over a large area. Labradorite felspar as usual. There is a very little iron ore and biotite.

Slide 2,588. *Olivine-norite.* Dyke, three miles W.N.W. of Dundee Trading Station; a dark-grey medium-grained rock with sp. gr. 2·98. Olivine abundant, changed to serpentine in a few spots, having very irregular outlines even when, as is usual, it is enclosed by the pyroxene. It may include felspar, augite and biotite. Augite is abundant, twinned in places and intergrown with enstatite, the two minerals being with difficulty distinguished from each other. They occur sometimes as large plates enclosing felspar prisms ophitically.

The labradorite is found in stout prisms, between which there is quite a considerable amount of more acid slightly clouded felspar, either albite or orthoclase, in places intergrown with quartz to form micropegmatite. The presence of quartz in a rock containing such a large proportion of olivine is a very uncommon feature indeed, and therefore deserving of special mention.

Biotite and long apatite needles are characteristic of the micropegmatite areas, the former being present in fair amount; iron ores are also not unimportant.

This dyke is probably one of the feeders which contributed to the Insizwa sheet.

Slide 2,606. *Olivine-norite.* Along road leading into interior of Insizwa Range, at a point about 1 mile west of contact on the Payne Syndicate's Area. A coarse-grained mottled rock with sp. gr. 2·95. Exceptionally large fresh olivines moulded on and including prisms of felspar; always irregular in outline. The augite and enstatite are intergrown at times, and either form a shell around the olivine or occur as patches enclosing the felspar somewhat ophitically or as irregular grains. In places, however, the felspar and pyroxene mutually interfere. There is a scarcity of biotite and

iron-ore; while minute amounts of acid felspar fill up spaces between the labradorite prisms.

Slide 2,599. Foliated *Olivine-gabbro.* A zone in the Insizwa sheet about 500 feet above its base, just north of Hornby's area, in the "poort" of the Umzimhlava River. A finely-banded rock resembling highly-altered dark-coloured sandstone dipping northwards at about 12°; sp. gr. 3·06.

The section which is cut perpendicular to the foliation shows a beautifully-banded gabbro, in which both the felspars and the ferro-magnesian minerals are arranged with their longer axes parallel.

The felspar is labradorite in rather small individuals arranged roughly in bands. The olivine is in a few cases in rounded grains, but the bulk of this mineral is in the form of extremely elongated individuals with a length occasionally of from 10 to 15 times their breadth, sometimes with straight sides and rudely pyramidal terminations, but more commonly having wavy outlines and being constricted in places. Augite is present in lesser amount, elongated also, but not as a rule to the same extent as the olivine; it sometimes occurs as rounded grains, commonly between or touching crystals of olivine. Some bands in the rock are rich in augite. Enstatite was not recognisable with certainty; biotite is absent, but iron ore forms minute crystals either attached to the ferro-magnesian minerals or isolated in the felspar.

Slide 2,600. *Augite-picrite.* Same locality as 2,599 alongside of which it occurs; this is the material of analysis No. 4. A dark resinous-looking brownish rock with specific gravity 3·23, accounted for by its extremely basic nature—43 per cent. of silica—and therefore the most basic variety of the Karroo dolerites that has yet been found. Olivine is extremely abundant, composing more than one-half the bulk of the rock, and is beautifully fresh and clear, though traversed by numerous cracks. The olivines have sub-rounded outlines as a rule, but where they come into contact with the felspar they are idiomorphic in habit. They are so numerous that they are frequently in contact with one another, but without having their boundaries interfered with; a few of the individuals are rather small. Augite is found in large plates which surround the olivines in the manner known as poikilitic—this structure is well shown in the hand specimens by reflected light; when in contact with the felspar the boundaries of the crystals are irregular.

The plagioclase is found in large, though skeleton, areas enclosing the olivines in a manner similar to the augite, and it probably crystallised only a little later than the pyroxene. It exhibits broad twin lamellae on both the albite and pericline plan, while cracks radiate outwards from the olivine crystals. The extinction angles indicate that it is a basic labradorite

approaching bytownite in composition; in a few places it is altered to a cloudy decomposition product. There is a little biotite and a number of crystals of iron-ore, the latter being rare in the olivine, though often occurring on the borders of the crystals of that mineral.

## ACID DYKES.

Slide 2,594. *Microgranite.* Vein cutting olivine-gabbro No. 2,593, Nolangeni Mining area. A very fine-grained light-grey rock with sp. gr. 2·67. Quartz is abundant in polygonal to rounded corroded areas, crowded together in places, while elsewhere the slide is fairly free from this mineral. There is also some acid plagioclase felspar in limited amount and somewhat clouded. The bulk of the rock consists of orthoclase felspar both in large plates and in small interlocking areas, always clouded, sometimes much so and with development of sericitic mica. Biotite is mostly represented by abundant flakes and tufts of chlorite, but in the larger crystals it is found almost unaltered. There is a good deal of ilmenite in small patches showing the change to leucoxene.

Slide 2,597. *Microgranite.* Vein in hornfels, Nolangeni Mining area. A very pale rock with minute dark specks; sp. gr. 2·57. The bulk is composed of orthoclase and plagioclase felspars, both clouded, and mostly with rudely rectangular outlines. Quartz ramifies between the felspar, forming in places a kind of micropegmatite. There are areas filled with chlorite (pennine), zoisite and epidote and, as the quartz and felspar exhibit crystalline faces in contact with these minerals, the patches may be drusy cavities filled in with secondary compounds. There is an abundance of irregular granules and aggregate of nearly colourless rutile scattered through the rock accompanied by flakes of chlorite and grains of zoisite. There is a little iron-ore included in the larger grains of rutile.

## THE METAMORPHISM OF THE SEDIMENTS.

The most striking feature of the Insizwa intrusion is the extensive and intense metamorphism of the sediments both above and below the sheet. In the former case the thickness of strata affected is at least 400 feet in places, while below the intrusion the induration is easily perceptible at a distance of some 200 feet as a rule. As the bluish shales and fine-grained sandstones are followed towards the contact they become harder, ringing under a blow from the hammer and fail to break so easily along their bedding planes. Ultimately they are converted into fine-grained blue-black or black rocks which break with a smooth conchoidal fracture, in which only

rarely can any minerals be made out with the unaided eye. At the contact and in inclusions the re-crystallisation has been such that only with difficulty is the originally sedimentary origin of the rock recognisable.

Great help is afforded by the preservation of the bedding planes and such structures as false-bedding; these are visible wherever the surface has suffered weathering, and the rock then possess a dark red-brown and roughish exterior.

Owing to the fact that successive layers differ firstly in texture and in composition and secondly in their distance from the contact, the beds are affected to different degrees at different points, so that specimens collected more or less at random along the zone of alteration represent a number of petrological types. The predominant material is a *hornfels* very fine in grain, the mineralogical constitution of which can only as a rule be well made out under fairly high powers of the microscope.

The clastic structures have been entirely destroyed and the hornfelses show an evenly granular holocrystalline mosaic, or what is appropriately termed a "pavement structure"; this is produced usually by quartz, cordierite, and felspar, and in this granular mass there are set small patches of the other minerals, chief of which is biotite. A very typical feature is the abundance of inclusions of quartz, etc., in certain minerals, principally in the biotite, cordierite, and enstatite, whereby the latter acquire irregular skeleton forms—"sieve-structure"—and sometimes such minerals are in consequence represented merely by scattered areas showing optical continuity. The shales and sandstones of the Beaufort beds contain a large amount of more or less weathered felspar, and under the thermal action of the intrusion, part or the whole of this felspar has been reconstituted; some hornfelses contain therefore a fair amount of both orthoclase and plagioclase felspar.

Cordierite is a frequent and sometimes abundant constituent, though when colourless it is very liable to be mistaken for felspar; in some cases it has been wholly converted into a mass of pale greenish chlorite—along with some colourless mica—in plates arranged more or less parallel to the vertical axes of the crystals. Biotite is ever present with characteristic strong pleochroism, and is sometimes accompanied by muscovite mica. There is always an abundance of iron ore, probably magnetite mostly, in the form of minute crystals disseminated through the hornfels, along with some apatite, zircon, rutile, and, in one case, tourmaline.

In the case of sediments which were originally somewhat calcareous, or contained calcareous concretions, lime-bearing silicates have been developed, namely, epidote, zoisite, diopside, enstatite, wollastonite, and garnet (probably grossular).

Close to the junction with the intrusive rock there appears to have been an actual diffusion of matter from the latter into the country rock, especially where the hornfels has been traversed by acid igneous veins. This is shown by the presence of basic felspar in the hornfels, while the occurrence in such cases of enstatite can probably be ascribed to the same cause.

As a rule the boundary between igneous rock and hornfels is a perfectly definite and sharp one, the former being quite coarse in texture right up to the contact, but now and then, especially in the case of inclusions in the gabbro, the one rock fades away into the other and a mixed or hybrid rock is the result, always on a small scale, however. At Insizwa, for example, the gabbro surrounding inclusions often exhibits a distinct zoning, following the outlines of the blocks of foreign material. The gabbro becomes richer in biotite at first, then paler and more dioritic looking, and merges into a white shell rich in felspar which borders the inclusion in the centre, here converted into a whitish quartzite-like rock.

In many places close to the junction the hornfels is impregnated with sulphide ores. To a considerable degree, though on a much smaller scale, the metamorphism at the Insizwa resembles that produced in the Pretoria beds in the Transvaal by the granite and norite forming the igneous complex of the Bushveld. It approaches nearest to the kind of metamorphism described by Mr. A. L. Hall* as the Groothoek Type, and found in the neighbourhood and along the contact with the central intrusion. It is interesting to find such resemblances in the contact metamorphism of strata which occur in such distinct areas and which differ so enormously in geological age.

The following is a petrographical account of some of the hornfelses collected near to or along the base of the Insizwa sheet:—

Slide 2,590. *Biotite hornfels;* south-eastern slope of Nolangeni mountain some distance from the junction. A very fine-grained banded rock with specific gravity 2·69. Quartz, orthoclase and plagioclase, form the bulk of the rock producing the usual pavement structure. Not improbably cordierite is present as well, but this cannot be decided with so much felspar in the rock. Biotite is fairly abundant with a few elongated prisms and some irregular grains of weakly pleochroic enstatite. Granules of epidote occur, along with an abundance of iron ores.

Slide 2,589. *Biotite hornfels;* same locality as 2,590, but close to contact; a slightly coarser-grained rock, specific gravity 2·71. This rock has apparently been impregnated by

1. A. L. Hall. On contact metamorphism in the Western Transvaal. Transactions Geological Society S.A., vol. xii., 1909

the gabbro, as it contains fully as much felspar as quartz, and the hornfels structure is not so well developed. Oligoclase felspar forms small prisms which are included in the orthoclase and quartz. The latter interlock and are intergrown so as to give a micro-pegmatitic structure in many places. A pleochroic enstatite is present in the form of elongated, though ragged, prisms, and in smaller areas biotite is abundant in small irregular patches, while the iron ore exists in the form of minute plates.

Slide 2,596. *Biotite-cordierite hornfels.*—Contact with gabbro, adit on Nolangeni Mining area. Quartz and felspar (orthoclase and plagioclase) form rather regular areas, the latter being often sharply rectangular in section. Cordierite is abundant, but practically entirely altered to pale chloritic pseudomorphs, still retaining rudely rectangular outlines. In certain areas the chlorite is deep yellow in colour; in others white mica has been developed during the alteration. Biotite is present showing sieve-structure often moulded on cordierite pseudomorphs, and itself changed in a few places to green chlorite; small grains of enstatite are common in certain parts of the section. There is a little zircon chiefly included in the biotite, apatite showing cores rich in dusty matter, and abundant crystals of magnetite.

Slide 2,598. *Biotite-cordierite-enstatite hornfels.*—Inclusion in gabbro from adit Nolangeni Mining area. Water-clear mosaic of quartz and cordierite, the former having polygonal outlines, or enclosed as blebs in the latter. In certain areas the cordierite is partially or wholly replaced by chlorite; felspar is probably present in small quantity. Conspicuous are large skeleton crystals of biotite and of enstatite, with pleochroism from bluish-green to brownish. Each of these minerals is riddled with inclusions and sometimes consist of grains detached from one another, but in optical continuity. The two minerals are also commonly associated, skeletons of the former appearing to penetrate similar incomplete crystals of the latter. The rock is crammed with minute crystals of magnetite distributed in an even manner and therefore included in the above-mentioned constituents.

Slide 2,601. *Cordierite hornfels*, contact with gabbro, MacGregor's Area. The structure of this rock differs somewhat from that of the usual type. There are long, well-shaped prisms of plagioclase felspar fairly free from inclusions and approaching labradorite in composition. The rock is crowded with cordierite, sometimes fresh, but more commonly altered; it is sometimes idiomorphic in habit. These minerals are enclosed and surrounded by quartz and orthoclase felspar, the latter occasionally forming large areas, and in a few cases making a delicate micropegmatite with the quartz. Enstatite occurs in small amount, while biotite is not abun-

dant, and then only in very small flakes with a little apatite and magnetite. The hornfels contains a large amount of chalcopyrite and pyrrhotite.

Slide 2,602. *Cordierite hornfels*, from at least 20 feet below the contact, MacGregor's Mining Area. The hand-specimen shows on the weathered surface elongated knots which in thin section are found to be composed of quartz, muscovite mica showing "sieve-structure" in places—sometime biotite—and a little felspar. The groundmass consists of a fine-grained mosaic of quartz, faint yellow cordierite, the latter always fresh and predominant, and skeleton biotites; these three minerals are crammed with minute crystals of magnetite.

The "knots" frequently run together to give small light-coloured bands, and are therefore probably in the nature of acid impregnations derived from the neighbouring basic intrusion.

Slide 2,609. Junction of dolerite and *epidote-hornfels*, close to base of gabbro, Payne Syndicate's Mining Area. The dolerite, which at this locality merges into the gabbro, is in the slide found to be an ophitic rock composed of plagioclase and augite with some olivine and magnetite, and is coarse-grained up to the contact with the hornfels, along which grains of epidote are concentrated. The hornfels consists of quartz and untwinned felspar, the latter showing zoning at times. The rock is full of epidote in irregular granules aggregated together without any definite orientation, and contains a moderate amount of iron ores and sulphides commonly associated with the epidote.

Slide 2,607. *Calc-silicate hornfels*. Payne Syndicate's Mining Area. Abundant garnet colourless to very pale yellowish in more or less rounded areas with irregular outline; aggregated together in places; full of patches of brownish-green chlorite. Predominant pale greenish diopside in fairly large areas moulded on garnet, but commonly idiomorphic with regard to wollastonite. The last-mentioned occurs in large, nearly colourless, areas surrounding the other minerals, and is sometimes twinned. Zoisite is present, but in limited amount; also sphene, forming elongated prisms grouped in bunches, at a few points. Chalcopyrite and pyrrhotite are conspicuous in irregular patches commonly bounded by dark green chlorite, moulded on diopside, but included in the wollastonite.

Slide 2,612. *Calc-silicate hornfels*. Large inclusion in gabbro, No. 1 adit Insizwa Mining Area. Abundance of colourless garnet in irregular grains, the smaller ones being included in the other constituents. Pinkish red to yellowish pleochroic epidote is conspicuous in very irregular crystals, which may enclose the other minerals ophitically. Compara-

tively large areas of finely twinned labradorite felspar enclosing an abundance of other minerals, namely, garnet, epidote, diopside, and a lesser amount of wollastonite both in colourless crystals with strong tendency to idiomorphic outline. Iron ores are absent.

The abundance of basic felspar is probably due to diffusion of material from the gabbro in which the inclusion stands isolated.

Slide 2,495. *Calc-silicate hornfels.* From adit No. 3, Insizwa Mining Area. Abundant colourless garnets clear as a rule and often idiomorphic. Wollastonite in prisms and grains mostly moulded on the garnet. Diopside predominating in great crystals enclosing wollastonite and garnet; it shows idiomorphic outlines to a colourless mineral which fills up spaces between the other constituent of the rock. It has low refractive index, moderately low double refraction and poorly developed cleavage, and is biaxial. The only mineral which it at all resembles is cordierite.

Slide 2,616. *Mixed rock*, adit No. 4, Insizwa Mining Area. This is taken from the acid zone bordering an inclusion of metamorphosed sandstone in the gabbro, and shows a type of rock intermediate between a granite (see Slide 2,594) and a hornfels.

There are large crystals of sometimes slightly clouded orthoclase felspar with interstitial quartz, and having strong tendency to idiomorphism. Through both these minerals there is scattered an abundance of small rectangular phenocrysts of a plagioclase felspar and crystals of slightly pleochroic enstatite with rounded corners generally, and areas of biotite. The latter has the sieve-structure characteristic of the hornfelses and is present in fair amount. Apatite is common in the form of slender needles, while there is also the unusual mineral tourmaline, blue in colour and in the form of bundles of small prisms.

## The Genesis of the Ores.

As already observed the copper-nickel ores occur along the lower junction of the sheet of olivine-gabbro, or olivine-norite, composing the Insizwa Range and never more than a few feet away from the igneous rock, so that the deposits are genetically connected with the intrusive material.

The gabbro must be regarded as the source of the ore, and a petrological examination of the ore-bodies shows almost beyond doubt that the sulphides formed portion of the magma of the once molten eruptive rock, and that during the cooling of the latter they segregated towards the lower edge of the intrusion, impregnating the adjacent strata to a small degree.

The evidence for this view will be presented under three

heads, each of which will be considered in detail, for the relationship of the ore to the rock has not only great theoretic interest for the geologist, but also a very practical bearing for the prospector and mining engineer.

These are: (*a*) The mode of occurrence in the igneous rocks. (*b*) That in the country rock. (*c*) The general habit of the deposits.

## (A) *The Mode of Occurrence in the Igneous Rocks.*

(1) The relationship of the three sulphide minerals to one another has firstly to be considered, and it is found that there is a definite order in which these constituents have crystallised.

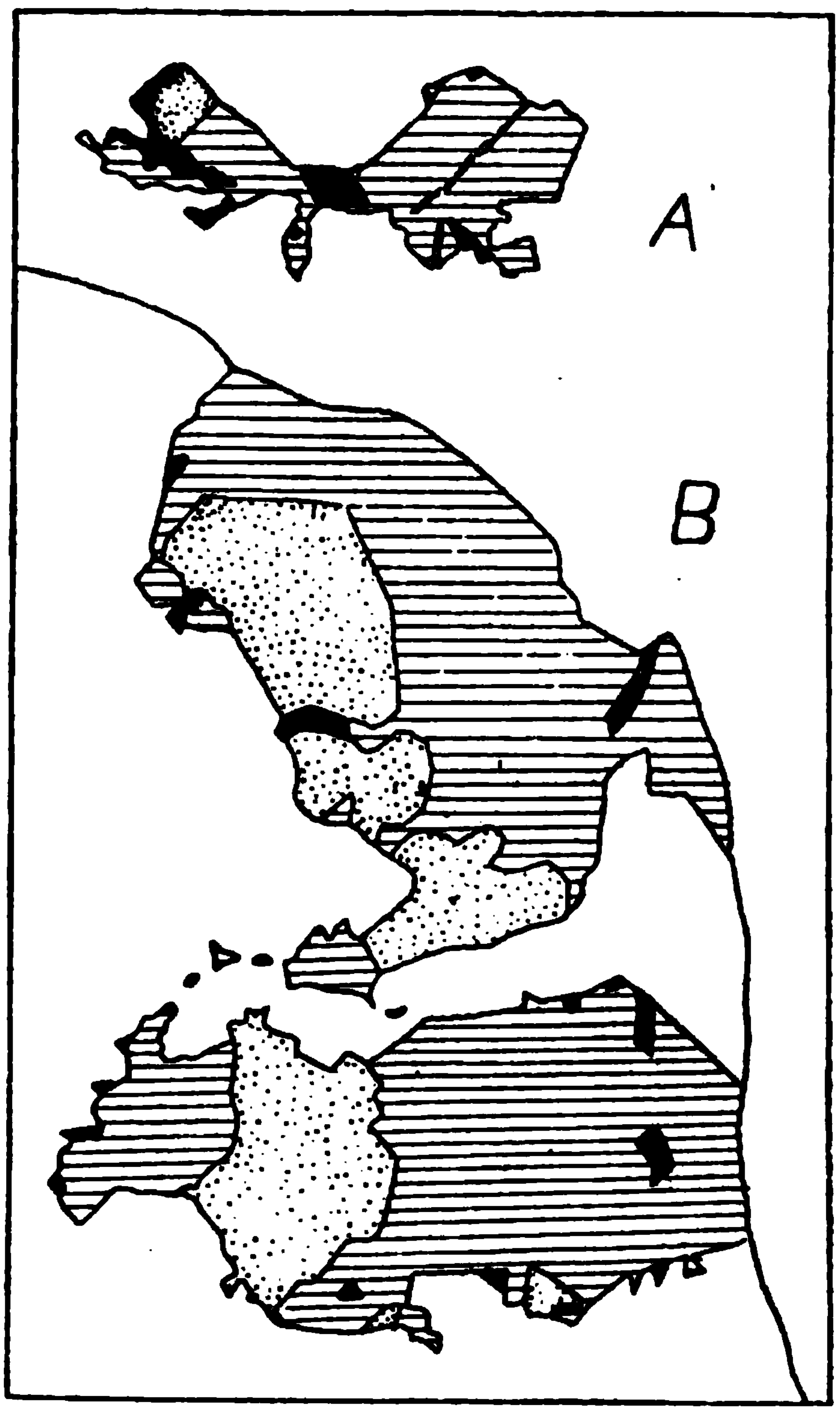



FIG. 3.—Showing integrowth of the sulphide ores (× 15 diameters). Chalcopyrite (black), pentlandite (stippled), pyrrhotite (ruled), silicates (left white).

In thin section the ores are, of course, opaque, but by means of reflected light more can be learned concerning the intergrowth of the sulphides.

For this purpose polished surfaces of the ore-bearing rocks were examined by reflected light under the microscope before

and after etching with diluted hydrochloric acid, a method applied by Messrs. W. Campbell and C. W. Knight[1] to various nickeliferous pyrrhotites.

In this manner the chalcopyrite can be distinguished from the pyrrhotite, and the latter in turn from the otherwise unrecognisable pentlandite, and the relationships of the three determined; diagrams are given in fig. 3 of such surfaces, fig. A corresponding to Slide 2,614 from the Insizwa Mining Area and fig. B to Slide 2,601 from MacGregor's Area. It will be noted (1) that the chalcopyrite occurs in small irregular areas which are usually in contact with the silicates and often in small angles formed by the latter; it is also the earliest sulphide mineral to separate out; (2) the pentlandite forms areas which often show crystal boundaries with regard to the pyrrhotite, by which it is partially surrounded. In the specimen it often exhibits the typical octahedral cleavage, this structure being brought out during the grinding process. The relationship of the pentlandite to the chalcopyrite is not very definite as a rule, but it seems to have been moulded on the latter in places and to have separated from the magma a little later therefore.

(2) The pyrrhotite, etching with a dark rough pitted surface, is the last sulphide mineral to form, enclosing, or partially surrounding, the other two. In places very delicate films or veins of silicate traverse this mineral in somewhat well defined directions, and therefore subsequent to its crystallisation.

The order of separation is, therefore:

(1) Chalcopyrite;
(2) Pentlandite;
(3) Pyrrhotite;

which is exactly the reverse of that obtained by Campbell and Knight in ore-bodies from Sudbury, Norway, etc., though the same peculiarity is present in these ores, namely, the growth of the chalcopyrite along the boundary of the ore patches and in areas isolated within the silicates.

(3) The relationship of the ores to the other constituents of the gabbro and norite are very well seen in thin sections (2,497, 2,614) of rock from the Insizwa Mine, and it is clear that the sulphides separated from the mother magma towards the completion of its solidification, and that they were not introduced by aqueous or hydrothermal agencies at some subsequent period.

Fig. 4 shows the finely idiomorphic outlines of the olivines when in contact with the ores, though the boundaries of this mineral against the pyroxenes are never so even and usually

[1] Economic Geology, vol. ii., p. 350, 1907. See also W. Campbell. Econ. Geology, vol. 1, p. 751, 1906.

a little irregular. The augite and enstatite also show idiomorphic or slightly rounded outlines in contact with the ores; and the latter are moulded on faces of the plagioclase felspars and have formed frequently in triangular-shaped spaces between the latter. The magnetite, never present in quantity though, is enclosed by the sulphides. The relation of the

FIG. 4.—Thin section (2614) of Olivine-norite Insizwa Mine (× 18 diameters) Showing relationship of ores (black) to the silicate minerals Olivine (Ol), Pyroxenes (Py), Labradorite felspar (La); and Biotite mica (Bi;—ruled).

ores to the biotite is more intimate, and it is probable that the separation of the ores (or of the chalcopyrite and pentlandite at least) took place at the same time as the crystallisation of the mica. In places the ore is moulded on the biotite, in others it is intergrown with it in a small degree, but commonly the mica forms a fringe around the sulphide areas. This close relationship has been observed in the Sudbury ore also.[1] The biotite and the sulphide ores were therefore the last minerals to separate from the magma. A most important point to notice as well is the fact that all the silicate minerals, including the olivine, are beautifully fresh and unaltered, and though the latter is traversed by the numerous irregular cracks characteristic of this mineral, no films of ore are found penetrating along these partings, nor along cracks or cleavages in any of the other silicates. In this way the Insizwa ores differ from some of the copper-nickel deposits that have been described, where the sulphides form veins ramifying through the silicates

[1] T. L. Walker. Quarterly Journal Geological Society, vol. 53, p. 52. 1897. A. P. Coleman. The Sudbury Nickel Field. Report Bureau of Mines. Ontario, p. 112, 1905.

and partially replacing them. In the vein-like streaks in the Insizwa rock the ore merely parts distinct crystals of the silicates and does not penetrate them.

It must be recorded also that the ores are not confined to the basic intrusive mass, but that the acid microgranite veins penetrating both the gabbro and the hornfels footwall are not infrequently full of small specks of sulphides.

### (B) *The Mode of Occurrence in the Hornfels.*

Ores are only found within a comparatively short distance from the gabbro contact, usually disseminated through the hornfels close to the junction, but sometimes forming distinct veins.

From the nature of the occurrence the ore must be of secondary origin, but, owing to the complete recrystallisation of the sedimentary material under the influence of the gabbro intrusion, the sulphides are not the last minerals to have formed. No doubt this reconstruction of the sediment went on simultaneously with the introduction of the ores, the latter being accompanied by a certain amount of felspathic material from the magma as well. In section (2,601) of a cordierite-hornfels from MacGregor's Area, octahedra of magnetite are often partly or completely surrounded by patches of ore. The latter is moulded on the plagioclase laths, but is earlier than the orthoclase, quartz and cordierite, and seems to have crystallised along with the enstatite.

In section (2,607) of a calc-silicate rock from the Payne Syndicate's Area the sulphide ores enclose magnetite, are moulded on the diopside, but are included in the wollastonite, which was the last mineral to form.

### (C) *The General Habit of the Deposits.*

(1) There is every stage from a gabbro or norite with minute scattered particles of ore to a rock in which ore and silicates are in equal amounts, and finally to an almost pure ore with a few patches of silicates scattered through it. These rich sulphide rocks may form roundish or oval masses, but more commonly give rise to sheet-like bodies running along or roughly parallel to the contact and grading into gabbro nearly devoid of ore. Only in a few cases do such segregations exceed a foot in thickness, but the gabbro is often rich in disseminated sulphides.

(2) The nature of the occurrences seems to be the same all along the line of mining areas, though for large distances the base of the sheet appears to be barren.

(3) The extremely fresh state of the minerals of igneous rocks containing sulphides has been adduced as an argument

for the magmatic origin of such ores. It is important, therefore, to note that no minerals such as almost invariably accompany ore-deposits formed by water action have been observed along the Insizwa intrusion. Quartz, calcite, chlorite, etc., are totally absent, which is most significant, for along the edges of Karroo dolerite dykes it is not uncommon to find occasionally narrow veins of quartz formed by waters ascending along the junction of the sedimentary and the igneous rocks; these usually show casts of the slicken-sided surfaces of the encasing walls.

The Insizwa sheet approaches closely in its form to the nickel-bearing intrusive of Sudbury, but, as we have already seen, the basin-shaped form is an original feature. The Insizwa rock, though much more basic than the Canadian occurrence, is very much fresher in character, while both rocks contain a certain amount of a rhombic pyroxene, enstatite or hypersthene. Again with one exception—the very basic horizon some 500 feet above the bottom of the sheet in the Umzimklava Poort—the intrusion decreases appreciably in basicity from the lower to the upper edge, and though at the top there is no distinctly acid granophyric rock present, olivine is sometimes absent and there is also a small amount of quartz and micropegmatite. This is proved by the silica percentages already quoted of rocks from different horizons, namely, 43 per cent. at the base, 48 per cent. half-way up, and 50 per cent. at the summit. This shows that there has been a differention of the mass to a limited extent, the more basic portion of the magma having gradually concentrated itself towards the base of the sheet. Another point to be noted is the fact that the gabbro or norite contains rather more abundant felspar and olivine and less pyroxene than the usual type of coarse dolerite, while again, and this is most conspicuous, the rock is deficient in magnetite and ilmenite. It is for this reason that the gabbro is so light-coloured in the field and also that its average specific gravity (excluding the very basic types and ore-bearing varieties) is only 2·96, whereas in the majority of the dolerites the density is a little closer to 3·0.

It seems as if the sulphies had partially replaced the iron oxides normally present in such intrusions, and that in settling towards the base of the molten rock during the cooling of the latter the ores had become entangled in the silicates that had already separated out from the magma.

It is most interesting to find, too, that the copper ores of Namaqualand (Cape Colony) not only occur in hypersthene-bearing dykes, the bornite (with chalcopyrite) being disseminated through the dyke material or collected together to form great masses, but that the ores appear to be original constituents of the igneous rock.

So frequently are copper and nickel ores found as magmatic segregations in basic and ultrabasic rocks possessing enstatite or hypersthene as to suggest that the metallic sulphides may have determined the partial or complete crystallisation of the pyroxene in the rhombic instead of the monoclinic system.

### *Conclusion.*

Too little work has been done to prove either the economic value of the deposits or their exact extent, but it is to be hoped that with development more will be learned of the nature of these interesting occurrences. No opinion can be given as yet as to whether the gabbro will become more mineralised when followed inwards below the range. The experience at Sudbury[1] has been that the largest ore bodies have been found where the norite projects outwards into the country rock or forms a dyke-like offset into the adjoining formation, while deposits of importance have seldom been found along a straight margin. No deposits again have been found any distance away from the margin, and none along the (upper) contact of the intrusive sheet with the overlying sediments. No ore-bodies have been discovered away from the main mass, except on isolated dyke-like intrusions of norite, which evidently were of the nature of feeders.

The reported occurrences of copper ores along the base of the Ingeli Mountain, and in the Tabankulu Mountain as well, induce one to hope that prospecting will ultimately lead to the discovery of ore-bodies of considerable economic value in this region, favoured as it is by an abundance of water, a fair amount of timber, and with a large native population, thus ensuring a constant supply of labour.

---

[1] A. P. Coleman, loc-cit, p. 19.

# INDEX.

O.



P.



Q.

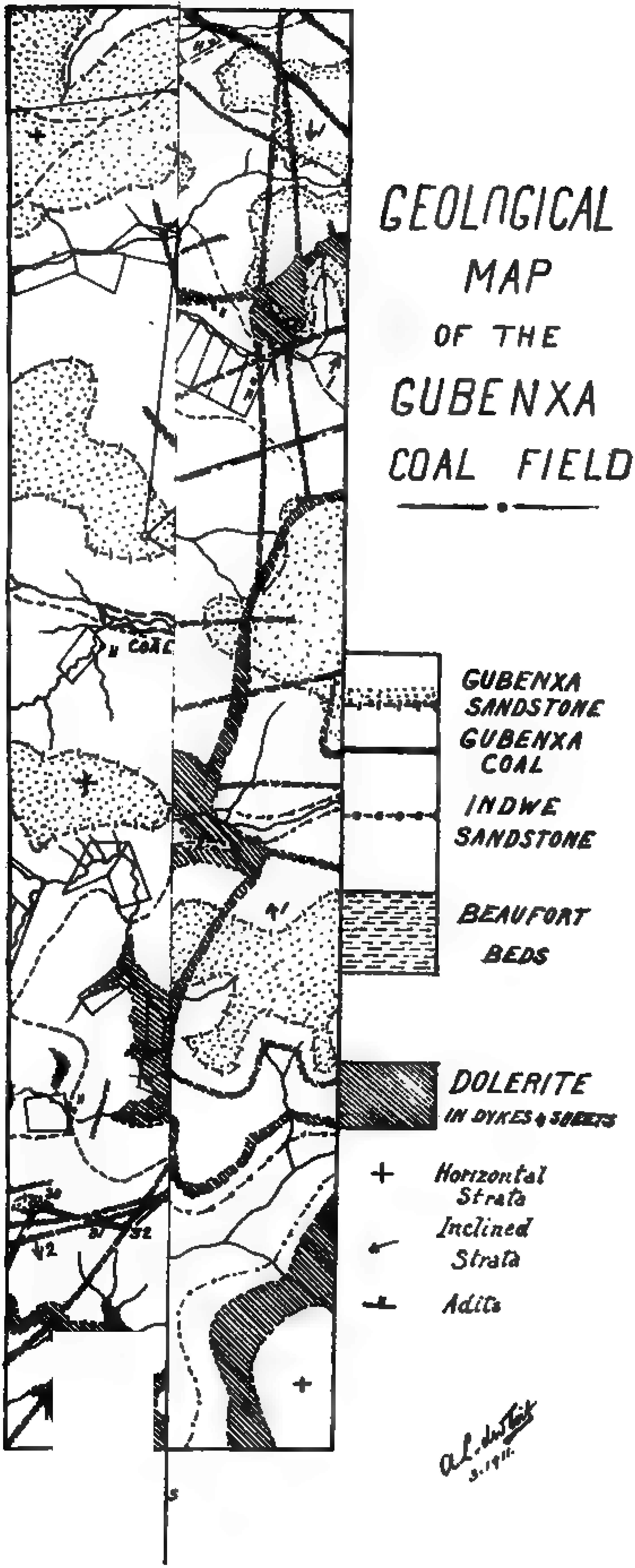


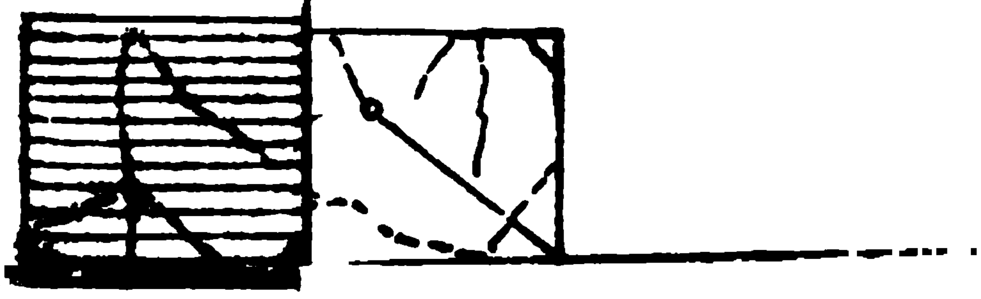
R.

S.



T.


GEOLOGICAL MAP OF THE GUBENXA COAL FIELD
COAL
GUBENXA SANDSTONE
GUBENXA COAL
INDWE SANDSTONE
BEAUFORT BEDS
DOLERITE IN DYKES & SHEETS
Horizontal Strata
Inclined Strata
Adits
A.L. du Toit
3.1911.



# CAPE OF GOOD HOPE.

DEPARTMENT OF MINES.

# SIXTEENTH

# ANNUAL REPORT

OF THE

# GEOLOGICAL COMMISSION

1911.

[redacted]

CAPE TOWN:
CAPE TIMES LIMITED, GOVERNMENT PRINTERS.
1912.

[U.G. 41.—1912.]

£72 2 2

B.572.1450.5.12.
C.T.Ltd.—B848

## ERRATA.

Fig. 2. (Map at end of Report) "South-east" should be "South-west."

Legend to Map of Telemachus Kop, "Intrusive dolerite generally in the form of sheets" refers to the cross-hatched area. "Younger dolerite dykes" refer to the heavy black lines.

Index Map, "Orange River Colony" should be "Orange Free State."

SIXTEENTH

# Annual Report of the Geological Commission,

1911.

---

CONTENTS.

# GEOLOGICAL COMMISSION OF THE PROVINCE OF THE CAPE OF GOOD HOPE, 1911.

## MEMBERS OF THE COMMISSION.

THE RIGHT HON. JOHN XAVIER MERRIMAN, M.L.A.

THOMAS MUIR, C.M.G., LL.D., F.R.S.
Superintendent-General of Education.

THOMAS STEWART, M.I.C.E., F.G.S.

ATHELSTAN HALL CORNISH-BOWDEN, Surveyor-General.

FRANCIS EDGAR KANTHACK, A.M.I.C.E., Director of Irrigation.

*Secretary*—
THEODORE MACKENZIE.

## SCIENTIFIC STAFF.

*Director*—
ARTHUR WILLIAM ROGERS, Sc.D., F.G.S.

*Geologist*—
ALEX. LOGIE DU TOIT, D.Sc., F.G.S.

Geological Commission,

South African Museum,

Cape Town, 1st May, 1912.

Sir,—

I have the honour to forward herewith the Annual Report of the Geological Commission of the Cape Province.

The correspondence that has taken place with reference to the Constitution of the Commission and its future position renders it difficult to add anything with reference to the progress made during the year to which the Report refers, beyond saying that for every reason it is most desirable that the future position of the Commission should be placed on some clear and permanent basis.

I have the honour to be,

Sir,

Your obedient servant,

JOHN X. MERRIMAN,

Chairman.

The Hon. the Minister for Mines,

Pretoria.

# GEOLOGICAL COMMISSION.

## THE DIRECTOR'S REPORT FOR 1911.

During the past year Dr. du Toit spent six months working in the Stormberg region and between Maclear and East Pondoland, thus completing the detailed mapping of a belt of country stretching from the Drakensberg to the Indian Ocean. The chief results of this work are that the beds above the Dwyka in East Pondoland previously called the Umsikaba beds, are shown to be more like the Ecca beds in the north of the Cape Province than the same beds in the western Karroo. The name Umsikaba is no longer required for the group; the strata called Idutywa beds in the 1901 and 1902 Reports, when their true stratigraphical position was not known, are shown to be Burghersdorp beds. The strip of Idutywa beds said in the 1901 Report to exist on the Kentani coast would seem to be part of the Lower Beaufort beds and cannot be part of the similarly coloured strata at Idutywa. The recent work carried down through the whole Karroo system shows that a separate classification for the Transkei is unnecessary. Another important point is the discovery of an area of Molteno beds on the coast south-west of St. Johns, near the Umgazana, where they are overlain by Cretaceous conglomerates like those of the Embotyi but fortunately containing some fossils of Upper Cretaceous age. The position of this mass of Molteno beds is due to a monoclinal fold and faulting. Though the lower Karroo beds were known to be disturbed near St. Johns, this is the first discovery of strata so high in the Karroo sequence on the coast of South Africa.

Further accounts are given of coal areas near Dordrecht, at Zadungeni between Elliot and Engcobo, and near Intwyenka between Maclear and Tsolo.

A description of the remarkable volcanic necks near Jamestown and the disturbances to which the Stormberg beds have been subjected in that area is included in Dr. du Toit's Report on part of the Stormberg.

Early in the year I spent nearly a month in the Transvaal in order to see some of the geology of that Province, and in connection with building stone. Thanks to the kindness of the geologists on the Transvaal Staff I was able to see much in a short time.

From May till November I worked in Van Rhyn's Dorp and Southern Namaqualand. The chief results of this work were the determination of the true order of succession in the Nieuwerust, Malmesbury and Ibiquas series, which can, by the help of the work done over 50 years ago by Andrew Wyley and the recent observations of Mr. Leipoldt, be correlated broadly with the Nama formation of German South-West Africa; and the discovery that there are gneisses both of pre-Nama age and of post-Malmesbury age in Van Rhyn's Dorp. The work done in the neighbourhood of the Copper Mines is not mentioned in the body of the Report because it was a preliminary step to a more detailed examination of the Copper Fields which will be made this year. A description is given of a group of nepheline-basalt pipes or necks, which can be indirectly connected with the pipes of Sutherland and Spiegel River.

The thanks of the Commission are due to Dr. Juritz and the Staff of the Chemical Laboratory for several analyses; to Mr. J. G. W. Leipoldt for much information and specimens from Namaqualand; to the Surveyor-General and the Director of Secondary Triangulation for maps and information; to Dr. Broom, of Springs, and Mr. Henry Woods of Cambridge University, for determination of fossils; and to Mr. G. C. Scully of Victoria College, Stellenbosch, for determination of alkalies in a nepheline-basalt.

During the past year two sheets of the coloured geological Map were issued, Nos. 11 and 13. Sheets 19 and 26 will shortly be ready for distribution. An index map showing the position of sheets published up to the present time is attached to this Report.

Part 4, Vol. VII., of the Annals of the S.A. Museum, published conjointly with the Trustees of the Museum, was issued during the year. It contains Dr. Andrew's description of the Plesiosaur from the Uitenhage beds and Dr. Broom's description of Dinosaurs from the Stormberg series.

ARTHUR W. ROGERS.

# GEOLOGICAL COMMISSION.

## General Abstract of Receipts and Disbursements for the Nine Months ended 31st March, 1911.

| Receipts | £ s. d. | £ s. d. |
|---|---|---|
| To Balance | 226 2 0 | |
| ,, Government Grant | 1,200 0 0 | |
| ,, Sale of Maps | 15 8 4 | |
| ,, ,, Oxen | 45 0 0 | |
| ,, ,, Horse | 20 0 0 | |
| ,, Hire of Wagon | 16 0 0 | |
| | | 1,522 10 4 |
| ,, Advances (Current), repaid by vouchers | | 105 0 0 |
| | | £1,627 10 4 |

| Disbursements | £ s. d. | £ s. d. |
|---|---|---|
| By Salaries | 750 0 0 | |
| ,, Allowances (Personal) | 167 3 9 | |
| ,, ,, (Horse) | 14 18 0 | |
| ,, Transport | 20 4 10 | |
| ,, Postages | 3 8 11 | |
| ,, Printing, Books, Magazines and Binding | 69 1 10 | |
| ,, Rock Sections | 4 0 7 | |
| ,, Boys' Wages | 23 17 0 | |
| ,, ,, Food | 11 5 11 | |
| ,, Purchase of Donkeys | 102 0 0 | |
| ,, ,, Scientific Instruments | 8 0 10 | |
| ,, Printing of large scale Maps | 129 0 0 | |
| ,, Maintenance | 89 0 7 | |
| ,, od for Donkeys | 1 6 8 | |
| ,, Horse Purchase Refund | 47 10 0 | |
| ,, Copyright of Maps | 3 5 0 | |
| ,, Miscellaneous | 2 7 8 | |
| | | 1,402 13 10 |
| ,, Advances made | | 105 0 0 |
| ,, Balance Refunded to Paymaster-General | | 59 16 6 |
| | | £1,627 10 4 |

This Statement was forwarded to the Department of Mines on 31st March, 1911.

THEODORE MACKENZIE, Secretary

# GEOLOGICAL SURVEY

OF

# PARTS OF VAN RHYN'S DORP AND NAMAQUALAND DIVISIONS.

BY

A. W. ROGERS.

# GEOLOGICAL SURVEY
OF
# PARTS OF VAN RHYN'S DORP AND NAMAQUALAND DIVISIONS.

By A. W. ROGERS.

## INTRODUCTION.

The district described in the following pages extends from the neighbourhood of Nieuwerust in Van Rhyn's Dorp to Garies in Namaqualand, and from the coast between Kwaas and Grauwe Duinen to the western edge of the Bushmanland plateau. It is continuous with the country mapped in Calvinia and Van Rhyn's Dorp in 1900[1], and in Van Rhyn's Dorp in 1904.[2]

Very few geological observations made in this area have been published. In the map attached to his " Report on the Copper Fields," by C. D. Bell, Surveyor-General, Cape Town, 1855, the existence of granite in Kamiesberg is noted. Wyley's work in Namaqualand[3] was not carried on so far south as Kamiesberg, but it is of great importance in furnishing a connecting link between the sedimentary rocks south of Kamiesberg and those of the plateaux in German territory. In Mr. E. J. Dunn's maps of 1872, 1878 and 1887[4] Kamiesberg is included in the region occupied by the north-western gneiss. Mr. J. G. W. Leipoldt recently sent a description of the sedimentary rocks near Steinkopf to the Geological Society of South Africa[5], and in several letters to the present writer he described various rocks and sections met with between Steinkopf and Van Rhyn's Dorp and sent down specimens and photographs to illustrate the descriptions. The observations of Mr. Leipoldt have been of much use in the course of the present survey, especially in pointing out a strong resemblance between the lower part of the Steinkopf beds and the Nieuwerust series, and between the upper part of the Steinkopf beds and the Ibiquas beds of Knegt's Vlakte; this resemblance led Mr. Leipoldt to suggest that the unconformities of the Nieuwerust series on the Ibiquas

---

[1] Ann. Rep. Geol. Com. for 1900, p. 21.

[2] Ann. Rep. Geol. Com. for 1904, p. 11.

[3] Reports on South Namaqualand; G. 35, 1856, and G. 36, 1857. Also the manuscript map hanging on a wall in the South African Museum.

[4] Geological sketch map of Cape Colony, London, 1874; Geological sketch map of South Africa, London, 1878, 2nd edition, Melbourne, 1887.

[5] Trans. Geol. Soc. S.A., vol. xiv., p. 20.

did not exist, and that the appearances were to be explained by faulting. This suggestion has proved to be correct, and the additional circumstance, that the beds in Van Rhyn's Dorp placed without hesitation in the Malmesbury series lie between the Nieuwerust and Ibiquas, has become clear in the course of the season's work.

The accounts of the travellers Le Vaillant, Lichtenstein, Paterson and Alexander are of much interest to anyone who visits the country they traversed, and they all stopped in the Kamiesberg, but the references to geology in their books are so slight that they have done little or nothing towards deciphering the structure of the country.

The chief result of the season's work, after the recognition of the true order of succession of the three members of what is evidently the equivalent to the Nama system of Great Namaqualand, is that there are two granitic gneiss masses in the area, one of which is older than the Nama formation and the other younger than the Malmesbury series, but whether it is also younger than the Ibiquas is not known. The district is made of the following rocks:—

Superficial deposits; Sand, alluvium, surface-quartzites and limestones.

The Dwyka series; tillite, shale and sandstone.

Nama System.—Ibiquas series, Malmesbury series, Nieuwerust series.

Schists enclosed by the older gneiss.

The igneous rocks are granite and gneiss older than the Nama formation and intrusive in beds of which the schists mentioned above are remnants; granite and gneiss younger than the Malmsbury series, possibly also younger than the Ibiquas; various dyke rocks, quartz-porphyries, diabase, dolerite, monchiquites and bostonites; and finally a number of pipes filled with nepheline-basalt.

## Physical Features[1] and Geological Structure of the District.

In southern Van Rhyn's Dorp there is a very marked drop in the surface of the country along the escarpment of the Bokkeveld. To the east of this escarpment lies the interior plateau, while to the west of it are the plains of Van Rhyn's Dorp and the Knegt's Vlakte[2]. The average level of these plains is about 1,500 feet below that of the country at the top of the escarp-

[1] The topography of the district is well shown on the Langeberg, Bowesdorp, O'okiep and Little Bushmanland sheets of the Reconnaissance series issued by the War Office. The series unfortunately ends at lat 31 ' and long. 19 in this quarter.

[2] Knegt's Vlakte is the name given to the northern part of these plains, but the southern limit of the Vlakte seems indefinite.

ment, but in the westward projecting spur of the escarpment near the town of Van Rhyn's Dorp, the Matsikamma Mountain, the edge of the interior plateau rises to a still greater height above the plain, probably between 2,500 and 3,000 feet. The Bokkeveld escarpment itself comes to an end at Stinkfontein Poort, but north of the poort a similar feature, though of different geological constitution, carries on the escarpment towards the Langeberg. The difference in geological structure north and south of the poort is brought about by the disappearance of the Table Mountain series, which caps the Bokkeveld escarpment. To the north of the poort the escarpment is formed by the Ibiquas series alone, or by that group and a capping of Dwyka; further north the Ibiquas group disappears, and the escarpment is formed either of gneiss or of gneiss with a capping of Dwyka. The breaks in the escarpment due to valleys eroded by streams descending from the interior plateau are more frequently met with north of Stinkfontein Poort than to the south, where the Table Mountain sandstones present a long curved line of cliffs to the plains. Probably the nature of the Table Mountain sandstone has contributed much to the present result, but there is also the circumstance that the streams draining the Calvinia portion of the interior plateau south of the Hantam (which is drained by the streams issuing at Stinkfontein Poort) are collected by the Oorlog's Kloof River which runs roughly parallel to, and just behind, the escarpment to join the Doorn River from the Western Karroo. Whatever the causes, the edge of the interior plateau has a very irregular form north of Stinkfontein, and there is no definite feature recognizable either from a distance or close at hand beyond the neighbourhood of Kamaboos. The Langeberg[1] is a part of the gneiss plateau capped by a thick outlier of Dwyka with a dolerite sheet on the top. Both north and south of it the west-flowing streams have embayed the edge of the plateau rather deeply; to the north-west the edge is in the form of a rather broken escarpment of gneiss, capped in places by outliers of Dwyka, and trending westward as far as Lieslap and Kamaboos. That part of the interior plateau lying north-east and north of the Langeberg is called Bushmanland, and it has an elevation of from 3,000 to 3,400 feet.

From the top of one of the steep sided hills of the north-eastern part of Knegt's Vlakte, such as Groot Klip or the hills of Lylyk Bakkies, which are of the "inselberg"[2] type, one has a magnificent panoramic view of the embayed edge of the plateau. In the neighbourhood of Kamaboos the fairly well

[1] Ann. Rep. Geol. Comm. for 1900, pp. 31, 47, 51.

[2] Inselberg (island mountain) is the name given to hills or mountains which rise steeply from a plain, thus giving a tract of country containing them the appearance of a sea with islands projecting from it. The essential feature is the abrupt changes of slope on all sides at the foot of the hill.

defined escarpment sends out towards the south long ridges of gneiss, of irregular shape owing to the many kloofs which have been cut in them; these ridges are an early stage in the production of the "inselberge" such as the hills of Groot Klip and Lylyk Bakkies, which are outlying portions of the formerly more extensive interior plateau. (See Fig. 1.)

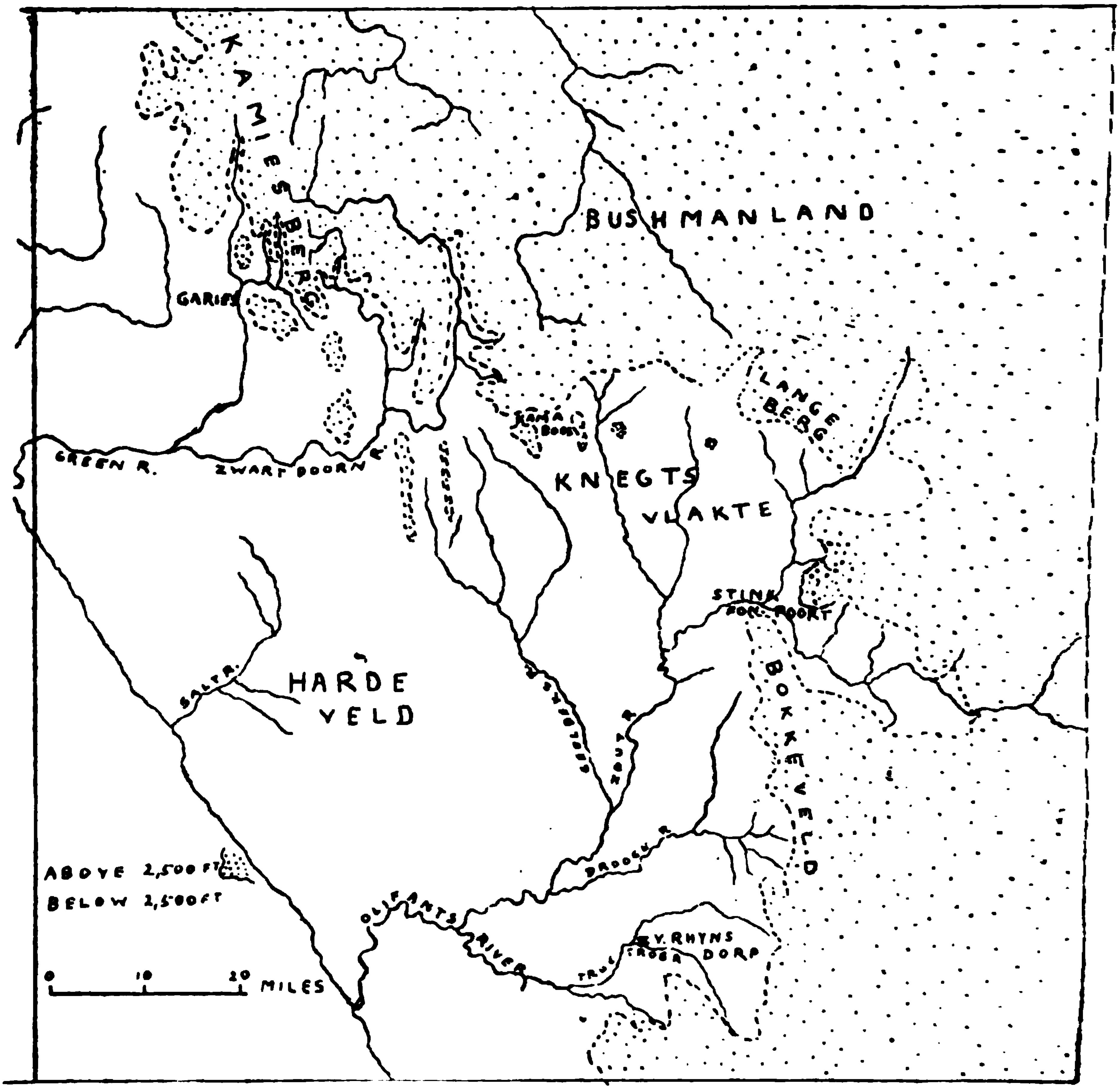



FIG. 1.—To illustrate the course taken by the edge of the interior plateau in Van Rhynsdorp and South Namaqualand.

From the top of the higher hills south of Kamiesberg one can also see that the whole of the country from the highest part of Kamiesberg to Bushmanland is really a fairly flat surface inclined gently towards the east. The height of the surface drops about 2,000 feet in 36 miles. In Kamiesberg and the country between it and Bushmanland the surface is found to be difficult to travel over with a wagon, owing to the river valleys

being very steep sided, but there are wide areas of flat ground, which become more and more the rule towards the east, and the impression got from a distance, that the country is a much cut up surface with general easterly slope, is maintained. Kamiesberg is, in fact, a western projection from the Bushmanland plateau which rises in height towards the west; it is, as a physical feature, comparable to the projecting part of the interior plateau, called the Matsikamma Mountain, near the town of Van Rhyn's Dorp.

The precise limits of Kamiesberg do not seem to be well defined in the local usage of the term, but it is applied to the mountainous country north of Groot Riet, west of the main road from Garies to Bowesdrop, south of the Buffel's River and west of Kauwgoed Vlakte. The country so limited is very deeply dissected by the streams going north to the Buffel's and south to Green River. The highest point, Ezelkop, 5,477 feet,[1] lies about 3 miles from a part of the valley on Wilgenhout River which is only 1,800 feet above sea level; and where the river is at 1,300 feet on Modderfontein the ground rises very sharply to Roode Berg, 4,700 feet, 5 miles to the east.

Kamiesberg is made entirely of gneiss and its enclosed schists, and the general strike of the foliation is roughly east and west. Most of the valleys draining the region have north or south courses, thus cutting across the foliation nearly at right angles. These valleys are often remarkably straight for several miles, and there are also chains of straight valleys separated by low neks, as on Riet Mond, on one line. In some cases, as on Draai Hoek and the farms to the north, the straight valleys mark the continuation in the gneiss of a fault (Koap Fault) which lets down the Nama system on the eastern side of a gneiss ridge. The effect of the deep valleys is to give the country south, west, and north of Kamiesberg a rather intricate shape, which masks the fact that the high country is a westward projection of the Bushmanland plateau.

From the fact that the outliers of the Dwyka series stand on the flat surface of more ancient rocks on the western side of Bushmanland, and that large parts of this surface have evidently been laid bare by the removal of the Dwyka by denudation, it seems that the old plain which rises towards the west is of pre-Dwyka age. The lower ground of Knegt's Vlakte, however, is a feature of comparatively recent date and one that is still being extended by denudation at the expense of the ancient plain. No outliers of Dwyka are met with at a lower elevation than about 3,100 feet in this part of the country.

Whether the eastward slope of the ancient plain, which carries it down through 2,000 feet in 36 miles, is an original

[1] A point determined in the primary triangulation of the Cape.

character, or whether it is due to subsequent tilting is a difficult question to decide. So far as is known there are no outliers of Karroo rocks west of Kamiesberg, in that region itself, or in any part of the Namaqualand—Van Rhyn's Dorp coast-belt. The level of the base of the Karroo system is still at about 2,700 feet in Gordonia and about 3,000 feet above the sea in Kenhardt, Carnarvon and Prieska along the outcrop of the northern edge of the main area occupied by the formation in those districts. The slope from Kamiesberg to Bushmanland is, therefore, unusually rapid for the base of the Dwyka. If a line be drawn on a map along the main anticlinal axis of Cederberg and extended northwards beyond the limit of the Cape formation it would pass through Kamiesberg, and the elevation of the latter region may have been connected in origin with the Cederberg folds.

Ridges made of older gneiss extend from Kamiesberg southwards into that part of Knegt's Vlakte made of the Nama formation. They are bounded on the east by faults along which some part of the Nama formation is let down against the gneiss, and on the west by the basal beds of that formation lying on a denuded surface of the gneiss and dipping westwards. Two of the ridges are some 20 miles long, from 3 to 5 miles wide at the north end, where they can first be distinguished from the general mass of the Kamiesberg, and only half a mile or less in width near their southern ends, where the gneiss outcrop is cut out at the surface by the eastern faults. These ridges are bounded by the Lang Dam Fault and the Koap Fault. The gneiss west of the Groot Riet Fault only forms an analogous ridge for about three miles, along the eastern side of the Een Koker outcrops of the Nama formation; elsewhere the gneiss extends uncovered by large masses of the Nama beds far to the west. East of the Nama beds which are brought down against the Koap Fault there is another gneiss ridge, partly bounded on the east by the Byzondermeid Fault, but it is not so regular a feature as the two first-mentioned. East of this again there are four or five analogous but much shorter ridges, for in this direction the throw of the faults becomes small, and the strips of the Nama formation are short and thin, small outliers of the basal series on a wide plain of gneiss.

These faults are the most interesting features in the structure of the country traversed last year,[1] and they are worth describing in more detail.

The general trend of the Groot Riet, Lang Dam and Koap faults is nearly north and south, with a tendency to turn towards south-south-east, which is more pronounced in the

[1] The country described is included in the Nieuwerust sheet (Sheet 19) of the coloured map issued in April, 1912.

smaller faults to the east, on Banker, Bushman's Graafwater and Uilklip. The throw is always to the east; the greatest throw along each fault varies from over 3,000 feet in the case of the Koap fault to perhaps only a few feet in the Meulsteen Kop fault. The throw cannot as a rule be estimated closely at any point because the identification of the highest horizon seen on the down-throw side is very difficult, and, excepting a few places where the base of the Nieuwerust bed still remains on the up-throw side, the amount of gneiss removed from below that horizon since the faulting took place is not known. The throw of the Koap fault diminishes rapidly northwards on Stof Kraal and Draai Hoek, by at least 3,000 feet in 9 miles.

The transverse faults on Draai Hoek, Stof Kraal and Groot Riet have northerly throws for the most part, but the long Byzondermeid fault has a throw to the south-west and apparently a south-easterly movement of the rock took place on the north side, but when it turns to the south the throw is on the eastern side as in the other north-south faults.

The fault which limits the Nieuwerust beds in the neighbourhood of Nieuwerust must have a considerable throw to the north and north-east. The Ibiquas beds are brought into contact with gneiss, and for some 12 miles the Malmesbury beds are not seen at the surface near the fault; the thickness of the Malmesbury series here is not known, and as the figures vary according to the amount removed by denudation in Ibiquas times as well as in consequence of original differences in thickness, the throw of this and other faults in the district must remain uncertain.

On Een Koker there is a block of Malmesbury beds surrounded by gneiss and Nieuwerust beds resting on it. There must be faults on all sides of the Malmesbury beds here.

The surface soil of Knegt's Vlakte contains much broken vein quartz, especially on the western side, and in the western part of each of the northern troughs. The quartz comes from veins filling fault fissures and other fissures which cannot be seen to be faults, probably because the exposures are not good and the rock on both sides of the fault is of the same kind. In several cases the continuation of the great faults south of the gneiss outcrops is marked by belts of vein quartz in the slates.

Cleavage is well developed on the western side of the troughs and in the western part of the Vlakte to the south, though the eastern outcrops of shaly rocks are not cleaved to any noticeable extent.

It is evident that the post-Nama earth-movements were most effective on the western side of the area as a whole, and also on the western side of each of the troughs at the north end of the Vlakte.

The granite and gneiss country west of Kamiesberg and the Knegt's Vlakte is hilly, though the tops of the hills decrease in height towards the coast and only reach 2,000 feet near Kamiesberg. The final descent to the coast is rather rapid, especially in the southern part of the area, just north of Salt[1] River mouth; generally, heights of 400-600 feet are found from two to four miles from the shore. A thick layer of red sand covers the rocks immediately behind the shore and for a distance of several miles (up to as much as 17) inland. On the shore rocks crop out at intervals, but there are no cliffs of noteworthy height, and none that are washed by the sea at low tide. There are long stretches of beach made of white sand, and the country behind the shore rises gradually and is covered with reddish sand.

The rivers draining the district either run directly to the Atlantic or join the Olifant's River. The Kamiesberg is drained by streams going north to the Buffel's River and south to Zwart Doorn and Green River. Knegt's Vlakte drains into Olifant's River, and the Hardeveld, a name locally used for the undulating and hilly country between the Kamiesberg and Knegt's Vlakte on the one side and the coast sand-veld on the other, is drained directly into the Atlantic for the most part.

The head streams of all the rivers coming from the Kamiesberg have high grades and steep sides. Through the Hardeveld the valleys are much more open and low graded, but for the last ten miles or so before reaching the sea they have steep sides. The short Salt River which rises in the Hardeveld has almost a cañon-shaped gorge for 5 miles, but the slopes of the sides become gentler at a distance of about 12 miles from the mouth; below this point the valley sides rise rather steeply for 100-200 feet, but above it they are precipitous for about 150 feet, and in places they are too steep to be climbed. For the last 12 miles of its course the Salt River has no outcrops on its bed, while the bed of the Green River is devoid of outcrops for about 20 miles. At the mouths of each of those rivers, and of the smaller streams between them, there are lagoons, wide expansions of the floors of the valleys cut off from the sea by sand banks which are broken through on very rare occasions by the river or by the river and sea together. The sea-ward ends of these valleys seem to have been depressed since they were cut to their present rock-floors, so that these floors have been buried under sand and mud brought down by the river and by the wind; probably the sea contributed to the deposits near the mouth.

The character of a great part of the coast line between the mouth of Salt River and Kwaas, when considered in separate

[1] Here, as in the Report for 1904, this river is called the Salt to distinguish it from the Zout River of Knegt's Vlakte.

sections, seems to be in agreement with the existence of the drowned valleys. Fig. 2 is a section drawn to scale through the coast at a point about three miles south of Green River mouth, and it is probably typical of a very large part of the coast in this district. The peculiarity is that the rock surface is carried upwards from the usual high water line in a very regular manner without showing a marked terrace cut by the waves. The terrace exposed at low water is at places perhaps 100 yards wide, but it has no continuation above the normal high water mark ending at a low cliff or bank of rock. At the place where the section in Fig. 2 was taken there are more exposures of rock (granitic gneiss) than usual, so that the approximate shape of the rock surface can be easily found. Usually the irregular accumulations of sand, on and behind the beach, hide the shape of the rock surface. A most important feature, however, the remarkable straightness of the coast in this part of the country, is quite opposed to the view that a simple subsidence alone is responsible for the whole shape of

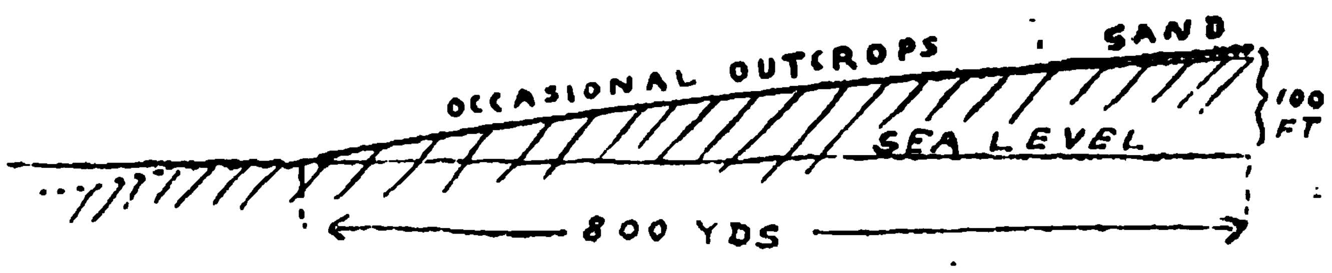



FIG. 2.—Section through the shore south of Green River.

the coast, for on no land surface would a contour line keep so straight a course over many miles. The straightness of the west coast has been taken as evidence of its origin through faulting.[1] It is difficult to accept this view, because faults parallel to the coast and with downthrow to the west are very unusual on the land itself. The only two noted in the area traversed last year are the short fault supposed to separate the older gneiss and Malmesbury beds on Riet Fontein (Salt River) and the similar one on Rondavel, and they are probably of great age. It is clear that the faults supposed to affect some hundreds of miles of coast line, and to cause its straightness, must be very young, for marine erosion has not had time to indent the coast line in accordance with the distribution of soft and hard rocks (Malmesbury schists and granite and gneiss respectively). The fault hypothesis seems to require confirmative evidence in the presence of similar faults affecting

[1] Hochstetter, Beitraeger zur Geologie des Caplandes, p. 28; Suess, Face of the Earth, vol. i., p. 338; Passarge, Die Kalahari, p. 596. In the last-mentioned work it is said that in Little Namaqualand Karroo beds appear on the coast, thus confirming the fault hypothesis, but so far as I am aware no description of the occurrence has been published, nor even its precise locality. It does not lie south of Kwaas, nor at Port Nolloth.

either the marginal portion of the inland plateau or the country between it and the coast. The former would be easily recognizable, for they would bring down the Karroo beds to the level of the country between the plateau and the shore, but no such faults have been found. The latter would be more difficult to detect because the geological structure of this coastal belt is not favourable, as faults affecting gneiss are obviously not easily found in an undulating country largely covered with sand. Such faults, however, would leave traces in the surface features for some time after their occurrence if the throw reached 20 feet or so. It might be expected that the agents of sub-aerial erosion would not be able to remove those traces of faulting more quickly than marine erosion would carve out bays in softer portions of the coast; we have seen that such bays have not been made, so we should expect to recognise faults in the coast belt if they exist and are of the age of the supposed coast fault. In Namaqualand and Van Rhyn's Dorp faults parallel to the coast in the country between the coast and the interior plateau would produce sudden steepening of the grades of the rivers flowing straight to the coast, such as the Green, Brak and Bitter Rivers, at points on or just behind the faults. These rivers, however, show no such steps; nor were any sharp interruptions in the continuity of long hill slopes noticed.

The suggestion put forward by Professor Penck[1] to explain features of the south-eastern coast, that its position is due to the intersection of the sea and a surface bent about a more or less horizontal axis, will explain the peculiarities of the Namaqualand coast, provided that the area concerned had already been reduced to a plain before the flexuring took place.

Along the Namaqualand and Van Rhyn's Dorp shore visited last year no evidence of the existence of raised beaches was seen.

## The Older Gneiss and Granite and the Schists Associated with them.

Granitic rocks older than the Nama system occupy the greater part of the country examined last year. They are on the whole gneissose, though occasional areas are seen in which the parallel structure is very little marked.

In the coastal belt these rocks form hilly country with comparatively few large outcrops, but in the Kamiesberg region and, generally speaking, at distances between 30 and 70 miles from the coast they appear in immense bare rounded crags and rocky hill-sides; beyond 65 or 70 miles from the coast they form the flat platform which is covered by the Dwyka, and the small tor called Gamoep on the western side of Bushmanland

[1] Sitzungsb. d. Königl. Preuss. Akad. d. Wissenschaften, xi, 1908, p. 230.

is the only feature of the kind seen in Bushmanland south of Koeberg, a gneissic range which was only seen in the distance. The great ridges and peaks of Kamiesberg are evidently due to the dissection of the Dwyka or pre-Dwyka plateau.

In spite of the parallel structure, the gneiss very frequently forms great curved surfaces without any joints or cracks visible from a short distance. These surfaces are abundantly developed in the Kamiesberg and the country to the north and south ; towards the west and east they decrease in size and frequency. One of the most conspicuous is to be seen in the peak called the Wieskind (orphan), at the head of the Green River Valley, where the bare rock slopes are over 500 feet in height.

The general trend of the gneiss in Kamiesberg and the country to the north, south and east, is some few degrees south of west, with steep dips to the west of north or east of south. There is thus a very marked contrast between the strike of the gneiss and that of the Nama system in the northern part of Knegt's Vlakte. In the coast region the strike of the gueiss changes much in direction, northerly and north-westerly strikes are frequent.

The gneiss generally contains biotite ; muscovite-gneiss or granite is very rare. The biotite-gneiss is frequently porphyritic owing to the presence of large crystals of orthoclase or perthite. The most conspicuous variety, which is found throughout the area occupied by the old gneiss, is a granulitic gneiss made almost entirely of quartz and felspar. This rock occurs in thick bands parallel to the foliation of the gneiss, as do all the schists associated with the gneiss. The outcrops of these varieties are often visible from a distance because these rocks generally break up under the influence of the weather slightly more rapidly than the gneiss, and they do not give rise to the great bare curved surfaces mentioned above. Their outcrops are marked by a thicker or more uniformly distributed growth of bush and deeper soil than are found on the gneiss itself. In spite of these circumstances it is as a rule much easier to obtain sound, unweathered specimens of the granulites and schists than of the typical gneiss, because the latter is almost always chemically weathered to a depth of a few inches on the outcrop, though it is not disintegrated, while the schists and granulites are less weathered chemically, although the outcrops are much broken up and hidden under the fragments so derived.

The bands of granulite and schist are of various widths up to 300 yards or even more, but they frequently include thin

layers of ordinary gneiss; and are found to have no definite boundaries on account of this feature.

The result of a microscopical examination of several of the gneisses and granites is that microcline and microperthite are usual constituents, and the biotite usually contains very slender needles which are probably rutile.

A grey porphyritic granite with slight traces of parallel structure forms large outcrops on Stof Kraal amongst gneisses. The large crystals of orthoclase lie parallel to the foliation of the gneiss. In thin section (2707) the constituents are seen to be quartz, orthoclase, oligoclase, biotite, zircon, apatite and magnetite. Micropegmatite of quartz and orthoclase and quartz and oligoclase, occurs in patches. The biotite is very strongly pleochroic, pale yellowish to almost opaque brown; it contains rutile needles. This rock forms bands separating foliated gneiss, and both are penetrated by coarse quartz-felspar pegmatite with reddish-brown garnets, usually in the direction of the foliation but not uniformly so.

Along the main road north-west of Garies granitic porphyritic gneiss cuts through a finer grained and more granulitic gneiss in all directions. The coarser rock (2711) consists of quartz, microcline (the predominating felspar), orthoclase, microperthite and an acid plagioclase; the porphyritic crystals are of microperthite; biotite, a very strongly pleochroic greenish-brown variety, with rutile needles; zircon, apatite, and magnetite. The darker rock (2712) has a more pronounced granulitic structure, and its component minerals are andesine-oligoclase felspars, microcline, quartz, red-brown biotite with much rutile, very slightly pleochroic enstatite, apatite, magnetite and zircon; pyrites is seen in the hand specimens.

To the west of the main road in this neighbourhood there are rather peculiar pegmatites traversing the gneiss; they are often only 3 inches wide, rarely as much as a foot. The central part is almost pure quartz, which grades into a felspar-quartz pegmatite, very poor in quartz, on the wall of the veins.

Veins of a more micaceous granite traverse the gneiss west of the Lang Klip hills in various directions across the foliation.

On Kromme Fontein the gneiss is crushed along N.N.W. lines, and the pegmatites have yielded less than the gneiss containing them, though they also show evidence of crushing. Bands of quartz-schist occur in the gneiss on Kromme Fontein.

On Dikdoorn along Green River there are thick bands of quartz-felspar granulitic gneiss. A thin section (2713) shows quartz, microperthite and microcline, and a few small highly-birefringent grains, probably zircon. Minute flakes of white

mica are the alteration products of the microperthite. A similar-looking rock from Rondavel Kop (2714) consists of quartz (with rutile needles), microperthite, microcline, some yellow epidote and a flake of altered biotite. The granitic gneiss on Rondavel is generally red; a thin section (2715) shows stained and partly granulitized quartz, microcline and microperthite, biotite, apatite, zircon, sphene and magnetite. There is much biotite-schist on Rondavel traversed by veins of granite. Below Nariep house there are larger outcrops of biotite-gneiss of which the general dip of the foliation is S. 10° E., but another set of folds has a N. 20° E. direction, and the gneiss is much puckered. On Roode Heuvel the foliation is often nearly flat. At Klip Kraal a prominent group of outcrops in the middle of the valley shows all stages between a massive granite and a highly-foliated gneiss; the latter contains more biotite than the less foliated rock and its minute structure is more nearly granulitic. In thin section the massive grey rock (2716) is seen to consist of quartz, microperthite, microcline, oligoclase, micropegmatite, greenish-brown biotite in which rutile needles are not abundant, a little muscovite, apatite, zircon and magnetite. The quartz is strained. A thin section (2717) of the foliated rock shows a distinctly more granulitic structure, but the constituents are the same as in the last, except that no muscovite is to be seen; small areas of micropegmatite are present, as in the massive rock.

Along the shore to the north of Green River mouth there are gneisses and massive granite, and about three miles to the north there are quartz-schists or very quartzose gneisses. In thin section (2719) this last rock is seen to be made of quartz, muscovite, a little yellowish pleochroic mica, some microperthite and zircon. Similar quartzose gneisses are seen on the right bank of Green River, behind the houses of Green River mouth, where there are intercalated bands of gneiss. To the south of Green River mouth various gneisses, porphyritic and massive, with small intercalations and fragments of highly biotitic gneiss and larger masses of quartz-felspar granulitic gneiss are seen at intervals down to the conglomerates of Karoetjes Kop shore, described under the Nieuwerust series. Just to the north of Brak River Mouth (north of Tities Bay) porphyritic gneiss forms a large mass of rock projecting into the sea without a sandy or fairly flat rocky shore, the only instance of the absence of a foreshore noticed on this coast between the south end of Geelwal Karroo and Kwaas.

Gneiss is seen at short intervals in the Brak River Valley from Nieuwefontein to the sea; most of it is porphyritic. There are occasional bands and irregularly-shaped masses of

biotite-schist, and veins of quartz-felspar rock without definite intergrowth of the two minerals frequently occur parallel to the foliation and less often across it; the quartz in these veins is white or milky, not transparent as in most pegmatites.

In the country between Nieuwefontein and Salt River porphyritic gneiss is the most abundant type. In the Salt River Valley the gneisses are very well exposed in the deep gorge between the mouth of Klein Goerap River and a point half a mile above the boundary fault on Riet Fontein. The section shows frequent alternation of porphyritic gneiss and a more massive fine-grained gneiss; and there are two bands of hornblende-schist, the thicker of which is 20 feet across. The foliation and the bands of the different varieties of rock are parallel, but the dip varies between W. 10° N. and W. 10° S.

In the valley of Zwart Doorn River below Stink Fontein there is much fine-grained reddish gneiss rather slightly foliated, a type which occurs to the west and south intercalated with the porphyritic gneiss.

The gneiss of Eendoorn (2748) is a well-foliated rock containing pale pink felspar. The constituents are strained quartz, microcline, microperthite, some micropegmatite, green biotite, magnetite and apatite. Much of the perthitic felspar consists of microcline and another felspar, instead of orthoclase and another felspar as is usually the case.

Rather over a mile to the north of Eendoorn house a belt of sedimentary rocks, traced eastwards and then east-south-east for 6 miles to the middle of Buffel's Fontein, is enclosed by the gneiss, which is foliated parallel to the supposed beds of the sedimentary rock. The reason why sediments are believed to be represented largely in this band, which is over 1,000 yards wide, is that there are quartz-schists, quartzite, and slaty rocks with felspar in them. A considerable part of the belt consists of quartz-felspar granulitic gneiss, rather coarser in grain than the grey or acid granulites of Prieska and Kenhardt. These pale granulites are often obviously banded, owing partly to the presence of more felspar in some bands than in others and partly to variation in the size of the component grains in different bands. The banded rock is often seen to be closely folded or puckered, though it is not sheared. A fair quantity of gneiss is intercalated with the rocks mentioned, and also some granite veins which do not run parallel to the foliation, but usually more to the north of west.

At one spot a good exposure is seen of a dyke of much sheared granitic rock traversing a finely-banded granulite, which is much less affected by shearing than the dyke. The shearing of the dyke produced a schistosity in a north and

south direction, nearly perpendicular to the banding of the granulite. In thin section (2749) the granulite is seen to consist of quartz, microcline, albite and apparently orthoclase (now represented by a cloudy substance containing much white mica), greenish-brown biotite with very many needles of rutile, magnetite, apatite and zircon. The minute structure is intermediate between granulitic and granitic. In places the biotite and quartz are associated in a peculiar way, numbers of small biotites lie parallel to one another in a single quartz individual, so that it is evident the two crystallized together. The sheared dyke (2750) consists of quartz, much altered felspar, but some acid plagioclase is still recognizable, epidote, some greenish biotite without rutile, magnetite, apatite and a little muscovite in fairly large plates.

A dark rock forming a band a few feet thick in this belt is a cordierite-sillimanite-gneiss. In thin section (2751) the constituents are seen to be quartz, cordierite, sillimanite, orthoclase, microcline, an acid plagioclase, a little greenish-brown biotite, zircon, green spinel and magnetite. The cordierite is abundant but is in part changed to a minutely granular and rather highly doubly refracting yellowish substance. Both the fresh and altered mineral have yellow pleochroic halos. Sillimanite is in fair-sized prisms, and it also forms very thin needles lying in the quartz, cordierite and the felspars. Another dark gneissose rock in this belt (2753) contains quartz, oligoclase, altered cordierite, a little greenish-brown biotite, magnetite and zircon. In the gneiss on Kliphoek, further up Green River than Eendoorn, there are streaks of dark rock up to 20 feet long by 6 wide in the gneiss. A specimen of one of these bodies (2789) consists almost entirely of alteration minerals, chiefly chlorite, enclosing remains of green-brown biotite and magnetite. No quartz or felspars were seen in it. A gneiss forming part of the enclosing rock (2790) consists of quartz, a little acid plagioclase, pseudomorphs of epidote and mica after other felspars, greenish biotite with much rutile, magnetite and zircon.

On Een Koker there is a band of apparently altered sediments stretching some 5 miles in a N.W. direction in the gneiss. They are greenish micaceous schists and quartzitic rocks, but under the microscope they appear to be sheared granulites of uncertain origin. A thin section from a micaceous outcrop (2703) shows strained quartz, much altered felspars, red-brown biotites (with rutile needles) arranged in parallel position and unaffected by the straining which is very noticeable in the quartz grains. A less altered granulite (2704) from Zout Fontein on the same belt has a similar composition, but there

is much fresh felspar (andesine). This belt includes some biotite-hornblende schist, on which a well (dry) has been sunk; both this schist and the granulites are traversed by quartz-orthoclase pegmatites.

On Wolve Gat there is a comparatively thin belt of felspathic quartz-schists and quartzites which make a ridge trending W.S.W. with the strike of the rock.

On Bitter Fontein and Hings Vley there are two long quartzite and schist belts north of the larger body of schists[1] on Roode Berg, Kranz Kraal and Nieuwoudt's Nauwte, with the strike of which they lie parallel. A granulite in the middle belt (2702) consists of quartz, andesine, red-brown biotite, magnetite, apatite and zircon; a few grains of pale-green augite occur with the biotite. The biotite in this rock is specially abundant in small flattened oval patches, about a tenth of an inch long, the arrangement of which gives the rock a parallel structure.

Another rock from the middle belt on Bitter Fontein (2804) is a garnet-gneiss with a fair amount of altered cordierite. The fresh minerals in addition to the quartz are garnet, perthitic felspar, and red-brown biotite.

A gneiss from Stink Fontein on the Zwart Doorn River (2803), a pink, well-foliated rock, consists of quartz, microcline, orthoclase, albite and microperthite, brownish-green biotite with rutile needles, zircon and apatite.

To the north-east of Garies the granitic gneiss is well exposed in the hills round the Sand River and the Wilgenhout River. Dark bands of gneiss up to 200 feet wide can be traced for various distances, but they disappear by thinning out or by becoming interlaminated by paler gneiss. Garnetiferous gneiss is abundant here, as in the Kamiesberg and much of the country north, east and south of the mountains. The dark gneiss owes its peculiarity to the abundance of biotite in it. The usual trend is W. 10° N. in this area, but in the Wilgehout Valley a long stretch of gneiss and schists has a N. 10°—15° E. trend, with a horse-shoe bend at the north end. There is much granulite in the gneiss, and pegmatites traverse all these rocks in various directions. Where the gneiss is puckered the pegmatite cuts through without being affected by the folding.

A grey gneiss from Modder Fontein (2793) is made of quartz, microcline, oligoclase-andesine, and a perthite in which microcline is predominant, greenish-brown biotite, apatite and magnetite. This is one of the few specimens of old gneiss in which perthitic felspars are not conspicuous constituents. A

[1] Ann. Rep. Geol. Com. for 1904, p. 30.

schist in this gneiss (2792), a greenish rock with much biotite, consists of brown-green biotite, actinolite, oligoclase, quartz, yellow epidote and chlorite. Biotite, actinolite and plagioclase are the chief constituents.

An interesting group of altered rocks occurs in the Wilgenhout Valley, between Modder Fontein house and the waterfall of the main stream. It is the band referred to above as being bent into a horse-shoe curve; the two limbs run parallel for some two miles before they become lost in the gneiss. The cave over which the river falls has great smooth walls and roof of gneiss enclosing strips and fragments of schists and granulite. The relation of the rocks is better seen on these surfaces than elsewhere in the valley, for the ground is very broken and bushy, though it would be difficult to break pieces of the enclosed schists out of the gneiss. Just above the cave a broad band of garnetiferous cordierite-sillimanite gneiss forms part of the schist belt. In the thin section (2794) neither garnet nor much sillimanite are to be seen, but quartz, microperthite, much cordierite partly altered, red biotite, magnetite and green spinel, zircon, and a single small prism of sillimanite. The characteristic rock of this schist belt is obviously an altered impure limestone, now largely made of wollastonite, diopside and garnet. The large wollastonite crystals matted together and enclosing red garnet and green diopside give much of the rock a remarkable appearance. The minerals are not uniformly distributed, but one or other of them occurs most abundantly in certain layers. In thin section (2795, 2796, 2797, 2799, 2800) epidote, carbonates, a white mica, a colourless micaceous mineral and some undetermined substances are occasionally present in addition to the three minerals named above. The wollastonite seems to have altered in places to a mixture of flaky minerals. There is at places some colourless mineral with very high refraction (nearly as strong as that of brownish garnet in the same slice) and very low birefringance. It is apparently uniaxial, and it may be idocrase; it occurs in bunches and does not show crystalline forms. A dark granulite is often found lying between layers of the lime-silicate rocks. The grain is much finer than that of the latter, in which the wollastonites may be an inch and a half long. In thin section (2798) the dark granulite is seen to be made of green diopside, plagioclase (in part at least labradorite), quartz and sphene. The felspar forms some large individuals with irregular boundaries enclosing rounded grains of all the other constituents. These rocks have a striking resemblance to some of the lime-silicate

schists and granulites of Kenhardt,[1] especially those of Mottels River and Nrougas Nord.

Crushed gneiss crops out near Modder Fontein in the valley floor. Fragments of gneiss are enclosed in a very fine-grained matrix of green biotite, quartz, epidote, felspar and minute flakes of white mica (2801). The Wilgenhout Valley, like several others in the Kamiesberg region, has a remarkably straight course which is maintained in spite of changes in the strike of the foliation of the gneiss, and which is continued in another valley to the south, separated from it by a low nek. It is quite probable that the valley has been excavated along a fault.

A large part of the gneiss on Groot Riet, Bloedsmaak and Draaihoek is porphyritic. A fresh specimen from a road cutting on Bloedsmaak (2802) consists of microperthite (both as porphyritic crystals and in the matrix), microcline, albite, orthoclase, biotite crowded with rutile needles, zircon and apatite. Micropegmatite is fairly abundant, both orthoclase and albite are intergrown with quartz. One crystal of microperthite encloses a peculiar round area of albite intergrown with quartz, the latter occurring in cylindrical bodies radiating from the middle of the rounded albite.

On Banker (in the northern part of Knegt's Vlakte) several bands of schists and granulite are intercalated in the gneiss ; the gneiss, schists and granulite often contain garnet. A dark granulite from the south-eastern part of the farm (2806) consists of quartz, oligoclase, altered cordierite, biotite and magnetite. A grey granulite near the last (2807) is made of quartz, a plagioclase, orthoclase, a colourless monoclinic pyroxene, tremolite, epidote, and a little magnetite. Epidote occurs in patches and small veins in the gneiss and granulites of this neighbourhood. Garnet is more abundant in the gneiss than in the granulites. There is a fair amount of rock with very slight foliation, and in it there are irregularly-shaped lumps of similar rock very rich in biotite.

The gneiss of the north-eastern corner of Knegt's Vlakte, on Kamaboos, Lieslap, Wiel Spoor, Warm Viool and neighbouring farms is chiefly a garnetiferous and porphyritic variety. The garnet is often an inch in diameter and contains inclusions of quartz and felspar ; it is much more abundant in the bands of gneiss without porphyritic crystals, and is apparently absent from the bands of quartz-felspar granulite, which look like hardened arkoses.

Near Padda Gas the fine-grained gneiss contains lenticles

[1] Ann. Rep. Geol. Com. for 1909.

of highly-siliceous ferruginous rocks up to three feet thick and 20 feet long. These seem to be of the nature of veins rather than inclusions, but the transition to the normal red gneiss is gradual and occupies about an inch.

On Paul's Kloof (Witwater) in the Kamiesberg there is a band of dark amygdaloidal schistose granulite in the gneiss, closely resembling the amygdaloidal granulites of the Marydale series in Kenhardt and Prieska. The amygdales are chiefly made of quartz, and they stand out on the weathered surface of the rock. Such rocks were not seen elsewhere in the district surveyed last year, but they weather more deeply than the gneiss and grey granulites found near them. They occur in a band, parallel to the foliation of the gneiss, on the south side of the river through Paul's Kloof. The amygdales are more or less spherical or ovoid in shape and of various sizes up to half an inch long. Under the microscope (2820, 2821) the constituents of the matrix are plagioclase which may range from andesine to labradorite in composition, strongly pleochroic red-brown biotite, hypersthene, magnetite, apatite and zircon. The quartz of the amygdales forms much larger individual grains than are seen in the rest of the rock. The structure is schistose owing to the constituents having their longer axes in one direction, and the biotite and hypersthene show this arrangement best. Apatite forms small prisms, but the other minerals are in irregularly-shaped areas with smooth outlines in typically granulitic fashion.

The rocks forming the prominent ridges and peaks of Kamiesberg, such as Ezel Kop and Roode Berg and the ridges east of them, are pink gneisses of varying texture, often with garnet. On these mountains the great smooth surfaces left by the breaking-off of curved slabs of uniform thickness (exfoliation) are very conspicuous, and they are met with on wide bands of uniform grain, either coarse or fine, and on mixed bands of coarse and fine grained gneiss.

On the road about five miles from Kauwgoed Vlakte, on the way to Witwater, some outcrops of biotite gneiss are in places stained blue-green with copper compounds, and when the rock is broken up the coloured films are often seen along the foliation planes. The rock (2822) consists of quartz, decomposed felspar, some of which is plagioclase, biotite, apatite, zircon, magnetite and a pale green spinel. No copper sulphides are visible in the rock examined, but the copper stains are probably due to the alteration of such sulphides once contained by the rock.

On Kopjes Kraal small outcrops of serpentinous limestone occur amongst highly foliated biotite gneiss. They lie some

500 yards S. 8° E. from Bruin Kop and cover in all an area of 30 feet by 5 feet; the arrangement of the serpentine gives the rock a parallel structure which coincides with the foliation of the gneiss. In thin section (2839) calcite and almost colourless serpentine without iron ores are the chief constituents, but some magnetite is present outside the serpentine grains and there are three small rounded grains of an unaltered mineral with fairly high refraction and double refraction; they show no cleavages and may be olivine or a monoclinic pyroxene. A very similar rock crops out on Onder Gamoep five miles to the N.N.E. This rock (2840) still contains olivine (forsterite ?) cores in the serpentine. These outcrops are not on the same line of strike, as the foliation is about W. 5° S. With the Onder Gamoep limestone there is associated sillimanite-cordierite gneiss (2841) made of quartz, cordierite, felspar, sillimanite, biotite, magnetite, zircon and green spinel. This rock forms a band quite 20 feet thick immediately north of the limestone. Bands of hornblende-schist not more than three inches thick occur in the gneiss on Onder Gamoep, but hornblende-schists are not abundant in the Kamiesberg region. A 20 feet band was seen in the Dabeep Kopjes.

The limestones just described are like some of those of Vyf Beker and Leeuw Kop in Kenhardt,[1] but no scapolite rocks have been noticed in Namaqualand.

Rather basic granulites become more abundant in the country north of Vaal Puts than elsewhere in the district, but they were not seen in such thick belts as in Kenhardt and Prieska. A dark granulite in the north-west corner of Kamiebees (2826) consists chiefly of a rather basic plagioclase, hypersthene, and colourless monoclinic pyroxene, red-brown biotite, magnetite, some quartz and a very little green hornblende. The structure is granulitic, but the grains tend to be elongated in one direction, so that the rock is slightly schistose.

In the gneiss on the south-west part of Riet Fontein there is a band of dark granulite (sp. gr. 3.11) about 300 feet thick. In places it becomes schistose, and garnet is abundant in parts of the rock. A section (2849) shows andesine-labradorite felspars, bluish-green augite, hypersthene, green hornblende, red-brown biotite and magnetite. The structure is granulitic, though the hornblende occasionally has prism faces developed. The two kinds of pyroxene form poecilitic areas occasionally, enclosing felspars, hornblende and magnetite.

A grey granulite about 50 feet thick is seen three miles from Riet Fontein on the road to Een Doorn lying between flaggy

[1] Ann. Rep. Geol. Com. for 1909, pp. 35, 36.

gneiss. It contains lumps of magnetite up to half an inch long and is penetrated by pink pegmatite. It is made (2850) of basic plagioclase, blue-green augite, sphene and magnetite.

Pegmatites are fairly abundant in the Kamiesberg region, but they are not so conspicuous as in Prieska and Kenhardt.

On Kauwgoed Vlakte and the neighbouring farms there are remarkable veins of coarsely crystalline magnetite running through the gneiss ; quartz is often seen with the magnetite, but it makes up a small part of the whole. Fragments of the rock lie on the ground in abundance, but outcrops are not often seen. In one case the outcrop of a magnetite-quartz vein was traced for 60 yards along the foliation of the gneiss of Moed Verloren (between Paul's Kloof and Kauwgoed Vlakte).

Some peculiar veins on Kaams are associated with pegmatites of pink orthoclase, quartz and biotite. The veins are not quite like the usual pegmatite, and they are made largely of translucent quartz with a smaller amount of white felspar, which is not intergrown with the quartz, and crystals of molybdenite as much as an inch in diameter. The molybdenite is scattered at random through the quartz. The largest vein of this kind seen is about 20 feet long and three wide at the most. Magnetite[1] occurs in the pegmatite with pink orthoclase, and so also does a peculiar titanium mineral identical in general character with that described from Steyns Puts and Nrougas Nord in Kenhardt.[2]

On the large gneiss outcrops below the Nieuwerust escarpment of Flamink Berg, in the north-west corner of Flamink Vlakte, narrow veins of a black rock traverse the gneiss in various directions, sometimes forming a rough network. The veins are rarely an inch wide, usually half an inch or less, but they are always sharply divided from the gneiss. The outcrops look as though the solid gneiss had been shattered and the cracks filled with the black rock. Small angular grains of quartz and pink felspar lie in the black matrix. On examining a thin section (2805) from one of these veins the rock is seen a to be a very finely crushed (or mylonized) gneiss. Small fragments of quartz, microcline, microperthite and acid plagioclase lie in a very fine-grained matrix of quartz, greenish biotite and epidote-zoisite minerals. This crushed gneiss evidently resembles very closely the " trap-shotten " gneiss of some charnokite outcrops in the Salem district of Southern India, so named because the black substance in the veins

---

[1] According to qualitative tests kindly made by Mr. W. Versfeld, the mineral contains appreciable amounts of manganese and titanium.

[2] Ann. Rep. Geol. Com. for 1909, p. 60.

was taken to be a fine-grained trap rock,[1] but subsequently Sir T. H. Holland[2] proved the black rock to be comminuted gneiss, broken and probably partly fused by violent movements of short duration.

The foregoing account of the ancient gneisses and schists shows clearly that in Namaqualand there are the remains of very old sedimentary and volcanic rocks dispersed throughout a great area of gneiss. The altered sedimentary and volcanic rocks are so like those called the Marydale beds in Kenhardt and Prieska that should there be many connecting links found in northern Bushmanland between the Kamiesberg limestones, amygdaloidal granulites and sillimanite-cordierite gneisses, on the one hand, and the same kinds of rock lying 200 miles to the east-north-east in Kenhardt, it will be necessary to put them in one group. At present too little is known of them in Namaqualand to justify such a course.

The question which was raised by the Kenhardt and Prieska rocks, whether any part of the gneiss can be proved to be older than the schists etc. of sedimentary origin, also requires an answer from Namaqualand, but at present there is no evidence for the purpose. As in most regions of gneiss there are many places where one variety can be seen penetrating another, and places where less foliated and highly foliated rocks are found in proximity, but it is doubtful whether these phenomena point to any considerable difference of age in the granites and gneisses yet examined.

## The Nama System.

Rocks belonging to this system occupy a wide area south of Kamiesberg and east of the granite and gneiss hills of the Hardeveld.[3] They occur again on the coast near the mouth of the Salt River, and in the Hardeveld as outliers.

The sub-division into Nieuwerust beds, Malmesbury beds and Ibiquas beds can only be made satisfactorily south of Kamiesberg; on the coast there is a difficulty, owing partly to want of sufficient outcrops to show the stratigraphical position of certain beds and partly to the complex structure; in the Hardeveld most of the outliers can be assigned definitely to the Nieuwerust beds, but there is uncertainty about a large faulted outlier along the Green River and also about a smaller one on Bruintjes Hoogte.

---

[1] King and Foote, Memoirs of the Geol. Survey of India, iv., part 4, p. 49.

[2] *Ibid.*, xxviii., p. 198.

[3] The Hardeveld is the hilly country (gneiss) lying between the sand-veld of the coast and the Knegt's Vlakte; Nieuwerust is on its eastern edge.

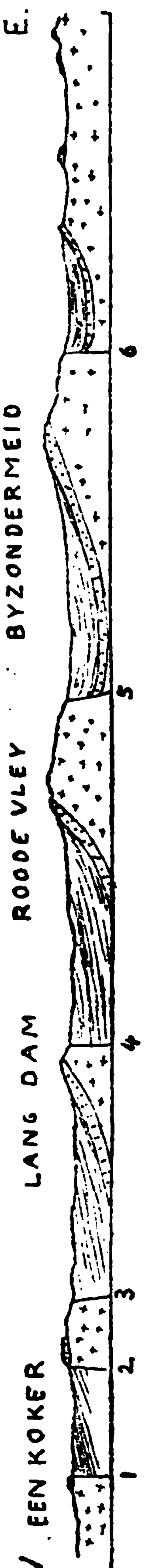



FIG. 3.—Section through the troughs of the north end of Knegts Vlakte, showing Nieuwerust beds (spotted) resting on gneiss (crosses) and passing under Malmesbury beds. 1–6, faults; 1, 2, Een Koker faults; 3, Groot Riet fault; 4, Long Dam fault; 5, Koap fault; 6, Byzondermeid fault. Length of section, 35 miles.

The structure of the northern and western parts of Knegt's Vlakte is shown on the coloured sheet No. 19 of the geological map of the Cape Province. The greater part of the Vlakte is made of slaty or shaly rock belonging to the Ibiquas series, but in the north and south-west similar rocks belonging to the Malmesbury beds occur over considerable areas, while on the farms between Duiker Vlakte and Kamaboos, and to the east of them, large parts of the Vlakte are directly underlain by gneiss or superficial deposits brought down by streams. The main area of the Nama formation of Knegt's Vlakte ends northwards in three strips thrown down to the east of the Groot Riet, Lang Dam and Koap faults respectively. The succession in each case is the same; on the east quartzites and arkose of the Nieuwerust beds rest unconformably on the older gneiss; the Nieuwerust beds dip westwards at moderate angles and pass under the Malmesbury beds, apparently conformably. In the easternmost of the three strips theIbiquas beds succeed the Malmesbury unconformably. A section across these faulted tongues of the Nama formation is shown in Fig. 3. To the east there are several smaller masses of beds belonging to the Nama formation thrown down on the east side of faults, which are roughly parallel to the three named above. The throws decrease rapidly eastward, so that only the Nieuwerust beds are preserved east of the TafelBerg area.

To the west of the Groot Riet fault only small patches of the Nama formation are found, till the coast and lower partof the Salt River valley are reached.

### *The Nieuwerust Series.*

This name was given to the arkoses, quartzites and shales lying nearly

horizontally on the granite and gneiss in the neighbourhood of Nieuwerust.[1] Though there is considerable variation in the character of the series over the area visited last year, no other rocks than those mentioned were found in it. No thick conglomerates, for instance, were found, though pebbles occur scattered through the coarser beds in places and occasionally form thin layers. The conglomerates on the coast and in the Green River valley cannot be definitely assigned to this series, though they may belong to it.

After the true stratigraphical position of the Nieuwerust beds in the country immediately south of Kamiesberg had been ascertained, a visit was made to the country near Nieuwerust in order to clear up the difficulty due to the supposed existence of an unconformity between the Nieuwerust beds and the Ibiquas and Malmesbury. The important area is the eastern boundary of the mass of Nieuwerust beds which extends from Nieuwoudts Nauwte to Bushman's Grave. In 1904 this was taken to be an unconformity, because the Ibiquas beds on the north-east, steeply dipping slaty rocks, crop out occasionally on the slopes of hills capped by nearly horizontal Nieuwerust beds[2]; and also because there were found some outcrops of slaty rocks, believed to be Ibiquas beds, in the middle of a wide poort on Spitz Berg, between the Spitz Berg hills to the north and the Karree Berg to the south-east, and both these ranges are made of Nieuwerust beds lying at low angles, below which the slaty rocks would be carried if their strike were produced in either direction.[3]

The explanation of the first point is that though there is an unconformity, the older rock is granitic gneiss; a fault skirts the hills and at places is occasionally sufficiently far from the Nieuwerust boundary to allow the gneiss to crop out on the slopes of the hills, though these slopes are much obscured by fallen debris. The Ibiquas beds on the downthrow (N.E.) side of the fault crop out more frequently owing to their position lower down the slopes. The position of the fault is in places marked by vein quartz as in the cases of many other faults in this district. A comparison of the section given in Fig. 4 with the north-eastern end of the section in Fig. 4 on p. 39 of the Ann. Rep. for 1904 will show the essential difference between the revised and the former interpretation of the Spitz Berg hills.

The explanation of the second point is that the shale outcrops on the flat ground in the Poort belong to the Nieuwerust

[1] Ann. Rep. Geol. Com. for 1904, pp. 35-40.
[2] Ann. Rep. Geol. Com. for 1904, p. 38.
[3] Ann. Rep. Geol. Com. for 1904, pp. 38-9.

series, which is not cut through by the river bed leading eastward to the Geelbek's River on Biesjes Vlakte. The gravelly deposits on this flat ground cover most of the rock and conceal the relations of the shale outcrop, but with the certainty of the order of succession gained south of Kamiesberg and a knowledge of the existence and position of the fault north-east of Spitz Berg and Karree Berg it is obvious that the shale outcrops lie on the south-west and upthrow side of the fault, and also that they belong to the Nieuwerust series, for similar shales form a subordinate part of that group. The circumstance that a comparatively soft rock is seen on a gravelly flat instead of the harder felspathic quartzites is due to the irregular deposition and erosion of the gravelly material.

The existence of the curved fault on the north-east side of Spitz Berg raises no new difficulty, as it is another example of

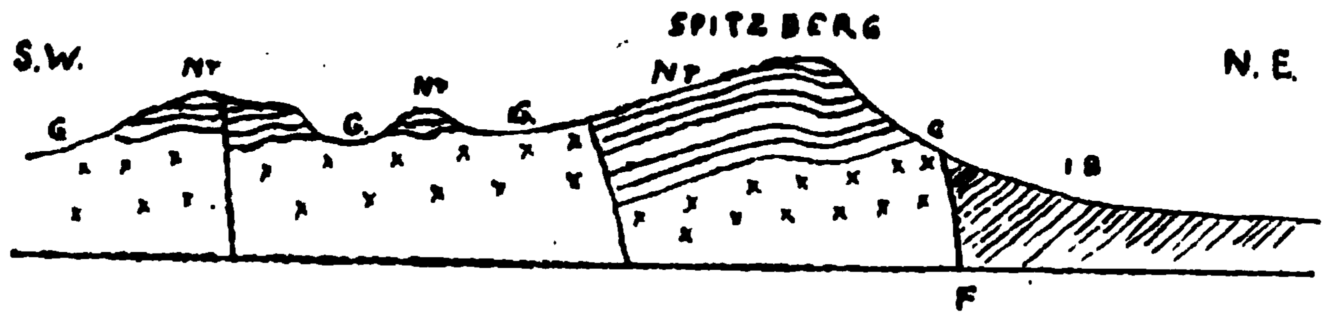



FIG. 4.—Section drawn through Spitzberg to show the unconformity on gneiss and position of fault F ; compare with Fig. 4 on p. 39 of the Report for 1904.

the group of faults with easterly throw found in 1904, and still more strikingly illustrated by the Groot Riet and other faults immediately south of Kamiesberg. The closest parallel to it is perhaps the curved Byzondermeid fault, which has a smaller throw in the opposite direction, *i.e.*, to the south-west.

The nature of the junction of the Nieuwerust beds with the Malmesbury on Groot Graaf Water could not be decided from another inspection ; the circumstances in general are like those on Spitz Berg and Bushman's Grave, but the slopes of the hills capped by the Nieuwerust beds are covered with débris which conceals the boundary. From the stratigraphy and structure of the country to the north-east it is now certain that this boundary must be a fault.

In the neighbourhood of Nieuwerust the series reaches a thickness of some 500 feet,[1] but further north the arkoses and quartzites lying below the shales and limestones, which must be regarded as belonging to the Malmesbury beds, are only 30 feet thick at places. The general rule is that in the country

[1] Ann. Rep. Geol. Com. for 1904, pp. 37 and 38.

south of Kamiesberg the Nieuwerust beds become thinner when followed towards the north or towards the east.

On the western or upthrow side of the Groot Riet fault arkose and quartzites of the Nieuwerust series form a range of hills trending nearly south-east across Hing's Vley to Kranz Kraal, where they are cut off by the Lang Dam fault. These beds lie nearly flat, and rest upon an eroded surface of gneiss and schists ; they are an outlier.

To the east of the Groot Riet fault the surface of the undulating ground on Ibiquas beds rises towards the arkoses and quartzites which flank the western side of the gneiss ridge of which the hill called Rheboks Fontein is a prominent point. The series can be followed 20 miles along the strike here, from Toontjes Vley to Twee Fontein, with a break of rather over a mile on Groot Riet, where two faults traverse the gneiss-Nama boundary obliquely, having a relatively raised wedge of gneiss between them. At the south end the Lang Dam fault cuts off the Nieuwerust beds, and the structure of the latter is further complicated by a S.W. transverse fault which makes a wide angle with the Lang Dam fault and shifts the southern end of the Nieuwerust outcrops to the north-east. For many miles the unconformity on the western side of the gneiss ridge can be seen at intervals. No conglomerates were noticed, though occasional pebbles of quartz are common in the felspathic grits and arkose. The most abundant type of rock is a bluish felspathic quartzite ; this type persists not only throughout the Rheboks Fontein range but over almost the whole area occupied by the series south of Kamiesberg. The more felspathic arkose tends to disappear towards the north as the whole series becomes thinner, and is entirely absent from some sections, as in the northern part of Groot Riet. All intermediate kinds of rock between a highly felspathic arkose, which weathers in much the same way as granite, and a quartzite almost without felspar, occur in the range. The beds are thickest on the southern part of Lang Dam and on Goud Vley, where they may reach 350 feet. The dip is westward, and the low ground at the western foot of the hills is much covered with gravel and sandy mud. The exact position of the Nieuwerust—Malmesbury boundary was not seen south of Groot Riet, where it can often be determined very closely or actually seen in section. There is no sign of unconformity along this junction, but the variation in thickness of the Nieuwerust series seems to be due entirely to changes in the amount of sandy or gritty material laid down over different parts of the area.

There is no evidence which enables one to determine and

compare the precise horizons of the uppermost or any other particular bed in the Nieuwerust series at different points, as for instance at the southern beacon of Lang Dam and the middle part of the outcrops on Groot Riet, where the beds are about 350 feet and 80 feet thick respectively. It is quite possible that the deposition of the grit went on longer at the one locality than at the other, or, again, that deposition was of equal duration at both while the amount differed. The dividing line between the Nieuwerust and Malmesbury beds is drawn where the change takes place from a group of beds mainly gritty to one mainly composed of shaly beds. There are gritty rocks far above the base of the Malmesbury in this area, but they are not likely to be confused with the Nieuwerust.

On Groot Riet and the eastern part of Twee Fontein the Nieuwerust outcrop curves round to the west and ends against the Groot Riet fault. Three small outliers still remain on the east and north of the main band.

To the east of the Lang Dam fault the Nieuwerust beds occur in a band very similar to the one just described. They lie on the western flank of the broken ridge of hills of which one outstanding portion is called the Koap Mountain. The length of the band is over 19 miles; it is fractured by the Byzondermeid fault, the northern portion having been displaced towards the east, and again by four faults on the north-eastern part of Groot Riet, three transverse and one strike fault, before being cut off entirely against the Koap fault.

The southern end of these outcrops forms a prominent rounded hill (beacon hill of Menschlief, Flennies Kraal and Onder Blauw Kranz), on which the dip is almost or quite vertical, and the strike is south-west. The general characte of the felspathic quartzites in this hill is so like the mo normally lying beds further north that it seemed more proba that they belong to the Nieuwerust series and have affected by at least two faults than that they are a porti the less altered of the sedimentary rocks lying in t gneiss. There are, however, very similar rocks amor latter, and their distinction from the Nieuwerust matter of great difficulty when the structure of the neighbourhood is not thoroughly understood. In t actual contacts with the gneiss have not been seen.

On Menschlief the Nieuwerust beds are about but they become thicker on Lang Dam owing beds becoming more abundant, and they thir 50 feet at the northern end of the outcrop

where the chief beds are reddish-brown felspathic quartzites. These ferruginous quartzites extend for some 14 miles from the north end of the outcrops past Modder Fontein (west of Stof Kraal).

A small patch of Nieuwerust beds lies on the west side of the synclinal trough of the Nama system on Modder Fontein, but on the downthrow side of the Lang Dam fault, the only instance of such an outcrop observed, for the other remnants of the Nieuwerust beds near the north-south faults are outliers on the upthrow side, such as those on Hing's Vley, Stof Kraal, and Tafel Berg (Dassies Water).

To the east of the Koap fault the Nieuwerust outcrops extend through 21 miles from Vliegemuis Gat to Draai Hoek, but are interrupted by the Byzondermeid fault, which shifts the outcrops to the south-east on its north-east side, and by three dip faults on Draai Hoek. The chief feature in this area is the marked thinning both at the north and south ends of the outcrops. The southern thinning may be due to denudation during the deposition of the Ibiquas, for the base of that series approaches the Nieuwerust outcrops very closely, and is probably in contact with them on Vliegemuis Gat. At the north end, where the Nieuwerust beds are only some 30 feet thick and make very slight outcrops, the Malmesbury beds are well developed, and the thinning of the former must be due to the conditions of sedimentation at the time.

The outcrops of Tafel Berg and the country to the south-east are less extensive than those described above; the top of the series, recognised by the coming in of the Malmesbury beds, is only seen in the Tafel Berg area, but there, and in the remaining areas, the Nieuwerust beds probably do not exceed 100 feet in thickness.

An interesting locality for seeing the base of the series is Meulsteen Kop at the south-east corner of Brandewyn's Kraal. Owing to the eastern slopes of the hill being gentle, the old surface of gneiss now in process of being laid bare by denudation is well exposed. The gneiss is a coarse variety with large porphyritic crystals of felspar, and it had weathered into great rounded boulders before the Nieuwerust beds covered it. The quartz-felspar grit or arkose of the latter filled up all the space between the boulders, so that the hard rock into which the gritty sand has been converted partly encloses the ancient boulders and fills all the crevices in them. The felspar of this grit is very little altered, and the rocks look not unlike a granite without mica.

Some 40 feet of Nieuwerust beds remain at Meulsteen Kop, and a particular bed has been found useful for making mill-

stones. This rock is a white quartzitic sandstone in which there is a fair amount of dull white material evidently derived from felspar. The quartz grains are rounded. In thin section (2803) under the microscope the material of the quartz grains is seen to have been removed from some of the contacts between neighbouring grains and deposited elsewhere, so that the grains now fit closely; their original boundaries are only visible occasionally, sometimes outlined by dusty matter in individual crystals made partly of an original grain and partly of subsequently deposited quartz. The dull white material is seen to consist of minute flakes and particles with high double refraction, probably sericitic mica.

At the base of the Nieuwerust beds on Leeuw Kuil, about five miles west of Meulsteen Kop, the old gneiss is overlain by a few inches of dark red mudstone, much finer in grain than any of the overlying beds, which are ferruginous felspathic quartzites or arkoses.

The largest area of Nieuwerust beds to the west of the faulted country described above is that between Een Koker and Kwanous. It is divided into two strips with south-easterly trend, separated partly by gneiss and in part by a faulted-down block of Malmesbury beds, recognised by the presence of white and grey-blue crystalline limestones and black shales. The Nieuwerust beds lie at low angles; they are arkoses and felspathic quartzites with occasional pebbly bands. To the north of Een Koker house there is a curious block of felspathic quartzites with northerly strike and almost or quite vertical dip. This is another instance of doubtful beds of felspathic quartzites similar to those at the south-east corner of Menschlief. There is an abrupt passage to the nearly horizontal Nieuwerust beds on the east, but neither at this boundary nor along the junction with the gneiss were exposures of the contact seen. The limits were put down as faults on the map. The thickness of these beds across the strike is too great to allow them to represent a single thickness of the series; if they belong to the Nieuwerust series there must be repetition by faults or folds that were not detected.

A faulted mass of felspathic quartzites on Bruintjes Hoogte has been assigned to the Nieuwerust beds, though there is much doubt whether they belong there or to the far older sedimentary rocks lying in the gneiss.

The mass is rather over three and a half miles long and nearly a mile wide at its broadest. There are not many outcrops, but the nature of the soil and the abundance of quartzitic fragments indicate the extent of the area occupied by the beds. A stream section shows the contact with the gneiss on the

western side at the north end. This junction is a fault, probably a thrust fault, along which the gneiss has moved eastward over the quartzites. Both rocks are sheared parallel to the fault plane, which is inclined westward at about 40°. Several feet of fault-breccia cemented by quartz separate the two rocks.

The reasons for regarding this mass as younger than the old gneiss and probably belonging to the Nieuwerust series are: (1) its lithological character, (2) the divergence between its strike (N.W.) and the foliation strike (W. 25°—30° S.) of the surrounding gneiss. Where quartzites and other sedimentary rocks older than the ancient gneiss were met with the two strikes are parallel, and the contacts, where seen, are not faults.

To the north of this mass on Bruintjes Hoogte there are three horizontally bedded outliers of Nieuwerust beds within three miles on and near the south-west boundary of Stink Fontein. They are made of bluish quartzites with little felspar, and more felspathic beds, in all 30 or 40 feet thick, with occasional quartz pebbles. In the outlier immediately south of Zwart Doorn River there is some gritty arkose.

To the south-east of Garies, east of the main road about four miles from the village, there is an outlier of Nieuwerust beds over half a mile long let down along a west-north-west fault, and on the south side of it. Two other outliers a few yards across are near this one. They consist of thin quartzites and arkose.

On the farm Paarde Kraal the hill called Paarde Kop, on the north side of Green River, is made of Nieuwerust beds, arkose and quartzites with some beds containing quartz pebbles. The beds are about 500 feet thick, bent into a shallow syncline with N. 10° E. axis. At the top of the hill some of the quartzites are ferruginous.

About seven miles further down Green River and on the south bank, on Rondavel, there is a large body of arkose, shale and quartzite which can be assigned to the Nieuwerust series, although it shows the effect of severe shearing on its north-eastern border, where the contact with gneiss is exposed in one place for about 100 yards. The Nieuwerust beds are highly micaceous for a few feet from the gneiss, and these mica-schists, which strike N. 30° W., enclose thin broken bands of quartzite. The gneiss, of which the foliation planes trend N. 10° E. a few feet from the mica-schist, has those planes dragged round parallel to the schists and the dividing line between them. The gneiss near this line is also highly micaceous, though lenticles of less crushed rock remain in it. The innumerable

the conglomerate is seen under the microscope to be a felspathic quartzite with marked schistose character. The original outlines of the grains are not visible, and the minerals have very jagged interlocking outlines and show the effects of strain. The felspar, orthoclase and microcline, are cloudy. There is a fair amount of white mica; rutile needles are enclosed by the quartz, and also a little magnetite and haematite. The rock appears to be an altered sediment.

An interesting feature in this sheared conglomerate is the occasional presence of coarse vein-stuff made of quartz and felspar in cone-shaped masses at the two ends of boulders wrapped by the schistose planes of the matrix. An instance of such deposits of quartz and felspar is illustrated in Fig. 6. The quartz is rather milky, and the felspar white or pale pink; a crushed fragment seen under the microscope is orthoclase with some thin lenticular interlaminations of another felspar

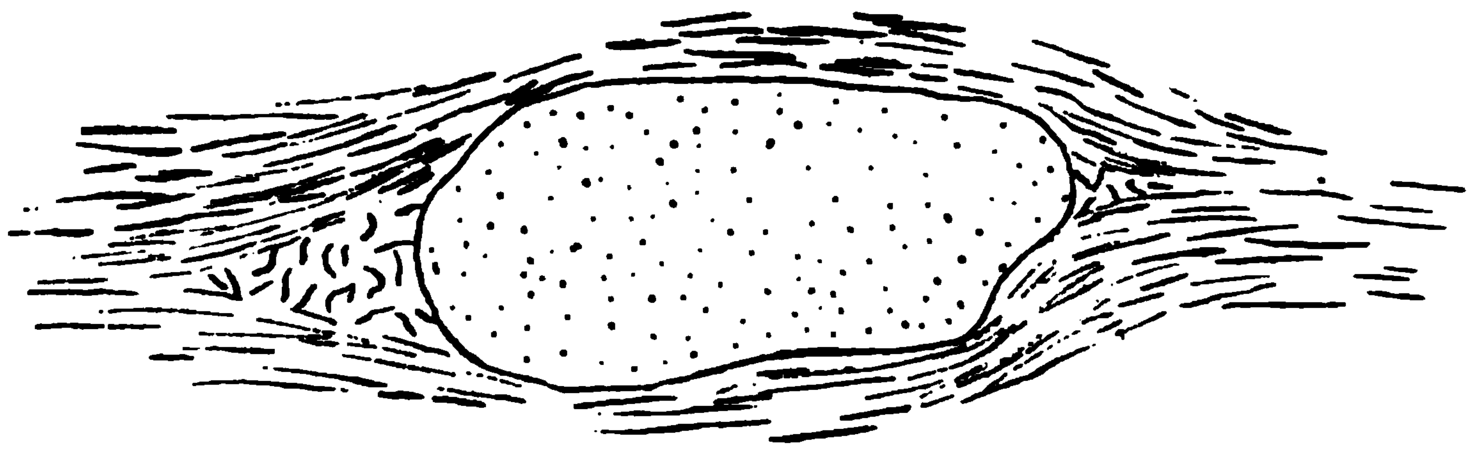


FIG. 6.—Boulder of felspathic quartzite in micaceous schist on Rondavel with cones of quartz-felspar vein-stuff at the ends.

after the manner of perthite. In addition to these two minerals there are thin laminæ of magnetite at places between the quartz and felspar. The general appearance of the quartz-felspar rock is that of pegmatites without regular intergrowth of the two minerals. In the case of the boulder represented in Fig. 6 the larger cone was five inches long (the boulder is about 14 inches long).

The arkose is very well exposed on the left bank of the Green River on Rondavel; the coarse gritty rock is in places largely made of pink felspar.

On Zonder Water Kraal, the north-western part of Pot Kley, a previously unnoticed outline of Nieuwerust beds was found. It makes no feature, but it is of interest because it contains pebbles of the old quartz-felspar rocks like the one described above from the Rondavel conglomerate.

The conglomerates and arkose on the shore of Karoetjes Kop and Grauwe Duinen can only be doubtfully referred to the Nieuwerust series, but they are more like the conglomerates

described above from Rondavel than the Ibiquas conglomerates of Knegt's Vlakte.

The best exposures of conglomerate are on the Karoetjes Kop shore, where they are seen at intervals for about two miles, below the level of high tide only. At the north-west end the conglomerates are bounded by coarse porphyritic gneiss, and the sea has worn a channel a few feet wide along the contact, which is covered with sand at low water. The conglomerate dips away from the gneiss, towards the south-east, for a few feet, then it has low south-westerly or west-south-westerly dips. There is great divergence between the foliation (striking about N. 10° W.) of the gneiss and the boundary and strike of the conglomerate nearest it, almost perpendicular to the foliation, so this contact can hardly be an intrusive one. This gneiss is regarded as part of the more ancient gneiss of the district. There may possibly be an unconformity, though the sharp dip of the conglomerate away from the gneiss, and its flattening and change of direction within a few feet make the presence of a fault here almost certain. No granitic veins were seen in these exposures of conglomerate.

The matrix of the conglomerate is a gritty mixture of quartz and felspar with much sericitic mica ; the rock has been very much sheared. The pebbles and boulders are not closely packed ; they consist of gneiss, quartzites, quartz and slaty rocks, the last being rather difficult to see because they have suffered much from the shearing and their limits have been almost obliterated. The largest boulder of gneiss seen, a porphyritic variety, is eight feet long. The general dip of the shear-planes is towards the west-south-west. A short interval of sandy beach separates the last conglomerate outcrop from the granitic gneiss to the south-west, which is supposed to belong to the later intrusions because the schists and limestones of the Malmesbury beds a little further along the coast are so highly altered.

At the south-west end of the outcrops of altered sedimentary rocks on this shore (Grauwe Duinen) a mass of gabbro separates the limestones on the north-east from a small body of pebbly quartzite or grit on the south-west, which is followed by gneiss (Fig. 7). The character of the junction is obscure, but the pebbly grit has an appearance similar to that of the Karoetjes Kop conglomerates. In a thin section (2742) the nature of the rock is less clear than in the outcrops, for it might be a crushed granite. Strained quartz fragments are abundant, chiefly angular but occasionally with rounded outlines. The felspar is very cloudy, and contains very much micaceous substance in minute flakes. Fairly large muscovite flakes are

frayed and bent; they may have been original constituents of the grit.

## *The Malmesbury Series.*

Hitherto the Malmesbury beds have been regarded as the oldest sedimentary rocks in the south-west of the Cape Province. They take their name from the Malmesbury district where they cover a wide area. Neither their base nor their top had been recognised, but all sedimentary rocks in the south-west older than the Cape formation and older than the large granitic intrusions have been placed in the Malmesbury series. Those pre-Cape sediments of the south-west which

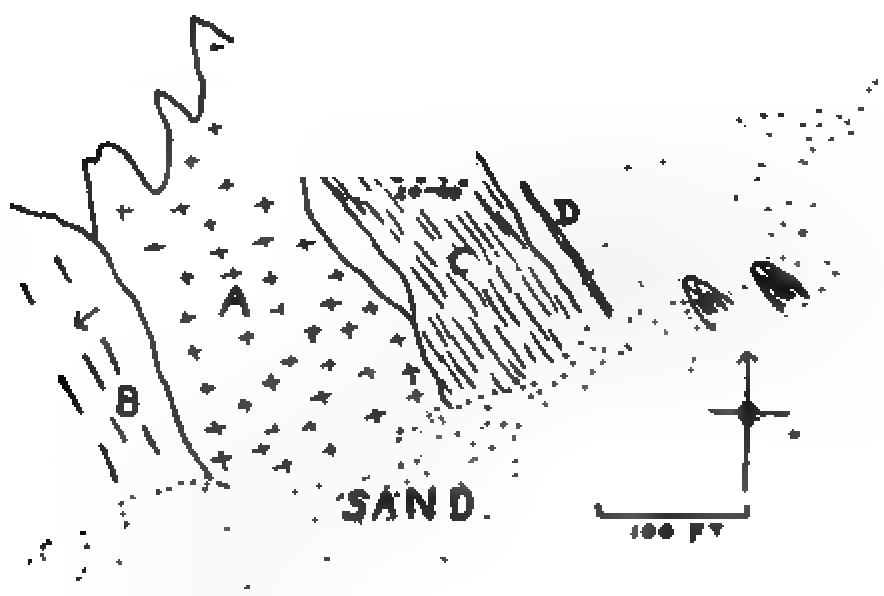



**Fig. 7.—Plan of gabbro outcrop (A) on shore of Grauwe Duinen. B, pebbly quartzite; C, limestone; D, acid dyke.**

contain boulders of granite and still older sedimentary rocks have been separated from the Malmesbury beds and given different names, Cango, French Hoek and Ibiquas beds.

In 1904 the Malmesbury beds in Van Rhyn's Dorp were found[1] to be divisible into three groups, the lowest consisting of black slates and phyllites (base not seen), a middle (*Aties* beds, from the farm of that name) group of limestones and shales, etc., and an uppermost of slates with quartzites and felspathic grits. This rough grouping is confirmed in the district surveyed last year, though it has become evident that the whole series is variable and that the limestones may disappear.

The continuity of these beds of Van Rhyn's Dorp placed in

[1] Ann. Rep. Geol. Com. for 1904, p. 13.

the Malmesbury series with the Malmesbury beds of Piquetberg and the Malmesbury—Cape Divisions is concealed at the surface by the Table Mountain sandstone which extends from the Olifants River Mountains to the coast.[1] There is no reasonable doubt that they are one formation, though the limestones are more prominent in Van Rhyn's Dorp than further south, where they are known near Piquetberg, at Vogel Vley, Worcester, near Ashton, and at a few other places. In each case the limestones are without intercalations of chert, and in this respect resemble the limestones of the Cango and differ from those of the Campbell Rand series in Griqualand West, Prieska, and the Transvaal.

Excepting the black shales and slates, which are generally of comparatively small thickness, the argillaceous rocks of the Malmesbury series have no general character or peculiarity which distinguishes them from similar rocks of other formations, so that their identification depends upon stratigraphical evidence only. Where this evidence is difficult to read, as is the case over a considerable area in the middle of the Knegt's Vlakte owing to the disturbed condition of the strata and also to the fact that the general scarcity of water has prevented a detailed examination of the whole district, it is impossible to separate the Malmesbury beds from the Ibiquas.

In the country immediately south of Kamiesberg, beds that are so like the Malmesbury beds of Aties and the neighbouring part of Van Rhyn's Dorp as to make it necessary to place then in the same group rest conformably upon the Nieuwerust bed This succession is seen best in the western and eastern of t three long north-south troughs of the Nama system, viz., the farms Groot Riet and Draai Hoek ; in the middle tr thick limestones were not seen, nor were they met with ir detached sunken area of Tafel Berg, though in the latte outcrops were not found at suitable places where the looked for, and circumstances did not allow a proper to be made along the whole of the horizon in questior

On Groot Riet the best sections are seen in the sma leading to the large river from the gneiss hills nor Byzondermeid fault and on the east side of the far streams have cut steep-sided poorts through the ha rust beds, here only some 80 feet thick, exposi conformity at the base. The hard quartzites are s soft shales rarely seen, which weather to a white but which are probably black when fresh ; th taken to be the base of the Malmesbury series

[1] Ann. Rep. Geol. Com. for 1903.

followed by at least five bands of limestone, generally bluish-grey with thin layers of white limestone, with which dark shales weathering white, pink or yellow, are interbedded. The limestone is sometimes very dark coloured. The grey limestones emit a strong smell of sulphuretted hydrogen when broken, as such rocks generally do. All the limestones are thoroughly crystalline, and no signs of fossils were seen in them. Analyses have not been made, but a considerable part of pieces tested dissolve in cold dilute hydrochloric acid, and the remainder only on heating, so that they are dolomitic. The total thickness of limestone on this part of Groot Riet is about 700 feet. Above the highest limestone seen there are over 1,000 feet of grey and brown shales with a few layers of felspathic quartzites near the top. The Ibiquas beds were not seen on Groot Riet.

This section is rather like the one described by Wyley[1] near the Orange River north of Steinkopf, where some hundreds of feet of sandstone or quartzite lie on gneiss and are succeeded by dark shales and limestones 350 feet thick, with a few sandstones and 1,000 feet of other rocks (presumably shales) above. This section described by Wyley is a connecting link with the Nama formation of German S.W. Africa, consisting of sandstones, arkose and conglomerates overlain by limestones and shales, which are unconformably overlain by another (Fish River) group of conglomerates, sandstones and shales.

On the southern part of Groot Riet the limestones are much less conspicuous than further north.

On Modder Fontein (the western part of the farm Stof Kraal on Sheet 19 of the coloured geological map) no thick limestones were seen, but the horizon on which they were expected is marked by numerous thin lenticles of limestone.

On Draai Hoek thick limestones occur in the same position as on Groot Riet, and they are well exposed, though further south on Byzondermeid they were not seen. The limestones on Draai Hoek are about 300 feet thick, including the dark shales interbedded with them.

On Een Koker there is an outlier of Malmesbury beds faulted down between hills made of Nieuwerust beds on the north-east and south-west, and between gneiss on the north-west and south-east. The rocks are rarely exposed, but thick limestones and black shales are seen behind the poort east of the homestead, and with them there are irregular beds or veins of black manganese and limonite, very like those in the limestones of Aties.[2]

[1] "Report on the Mineral and Geological Structure of South Namaqualand," G. 36, 1857, Cape Town, p. 5.
[2] Ann. Rep. for 1904, p. 17.

Pseudomorphs of limonite, or a mixture of limonite and silica, often over an inch in length, after pyrites are very abundant along the outcrop of an horizon some 1,200 or 1,500 feet above the base of the Malmesbury series on Byzondermeid and Groot Riet. They have evidently been left behind on the removal of the shale by wind and rain.

In the last eight miles of the Salt River before the wide lagoon is reached, and on the neighbouring coast of Karoetjes Kop and Grauwe Duinen, there is a great thickness of mica-schist with occasional more quartzitic bands; on the coast there are also thick white and bluish crystalline limestones. These rocks are very like the altered Malmesbury beds of Moed Verloren and Klip Drift Extension at the contact of the Moed Verloren gneiss,[1] where they are not nearly so well exposed. The outcrops on the coast and along the Salt River are evidently in an analogous position to those of Moed Verloren, and the slates of Hartebeest Kom[2] and Kokenaap are probably intermediate connecting links.

The nature of the boundary which crosses the Salt River in a north-westerly direction and separates the ancient gneiss on the north-east from the Malmesbury beds on the south-west could not be made out with certainty, but from the presence of brecciated rock in a few outcrops and the want of parallelism between the foliation of the gneiss on the one hand and the strike of the schists on the other with the probable position of the dividing line, that boundary is regarded as a fault with downthrow towards the coast. The actual contact of the two was not seen. Owing to concealment under sand the course of the supposed fault cannot be followed far; its course must soon end towards the north-west, for the outcrops on the coast on Karoetjes Kop show no evidence for its existence there, unless it makes a sharp bend to the west, and towards the south-east the conditions of the known structure do not necessitate its existence on Hartebeest Kom. It is almost the only known indication of faulting with seaward downthrow parallel to the coast in this part of the country.

The rocks exposed in the lower part of Salt River and the last few miles of Groot Goerap River, where the Malmesbur beds have been deeply cut into, are in a very poor state preservation. They crumble up when struck, excepting quartzite bands. The pegmatites and thin layers of intercalated with the schists have their felspars decomposed.

[1] Ann. Rep. Geol. Com. for 1904, p. 17.
[2] Ann. Rep. Geol. Com. for 1904, p. 13 and map.

The most abundant rock is a highly micaceous schist made of greenish and silvery mica, quartz, a very little garnet and scattered opaque grains of metallic appearance which are slightly magnetic and are probably ilmenite. Quartzites and felspathic quartzites are interbedded with these schists.

In the lower part of Groot Goerap River there is a hard band, three feet thick, of a mica schist with abundant patches of a brownish mineral looking like garnet in the outcrop and hand-specimens, but in thin section (2746) it is seen to be staurolite. It does not occur in well-formed crystals large enough to be seen by the naked eye in this rock, though it does so in some outcrops of a soft, rotten schist band two feet thick further down the river, and again in a ravine on the left bank of Salt River about half a mile from the bed where salt is collected. The hard staurolite-mica-schist mentioned above is seen under the microscope to consist of biotite and staurolite. with small amounts of chlorite and magnetite. The biotite is a rather pale variety, colourless to a moderately deep brownish green with the short diagonal of the nicol parallel to the cleavage traces. The staurolite occurs in grains and partly developed crystals aggregated in patches, and in smaller grains and crystals scattered thickly through the biotite and chlorite. The characteristic pleochroism is displayed by the small grains as well as the larger. Chlorite occurs in fairly well defined crystals, the largest individual minerals in the rock, but it does not seem to have been derived from the biotite as there are no individuals partly made of both. It is extremely pale blue and slightly pleochroic.

Within a few inches of the staurolite schist in the ravine on the left bank of, and about half a mile from the Salt River, there is a decomposed felspathic mica-schist which has very narrow streaks of blue-green copper stains in it. No sulphide ores were seen in the rock, and from the very small indications, which have only been seen over a few feet of rock, it would seem that the occurrence is of no importance.

The Malmesbury schists are much better exposed on the shore, where erosion performed by the sea removes the disintegrating rock. It is, however, worth noting that the mica-schists and limestones withstand the action of the waves almost as well as the granite and gneiss, as is shown by the fact that the very slight curves of the shore are not noticeably accentuated where the schists appear, though perhaps the proportion of sandy to rock shore is larger in the schist area than where the granite and gneiss occur. It is much easier to obtain sound specimens of the Malmesbury beds than of the granitic rock on the shore, because the latter weather to a

considerable extent without losing their power of resisting erosion.

To the north of the mouth of Salt River, on the shore, the first outcrops are sheared quartzites, arkose, pebbly quartzites, limestones and sericitic schists dipping between south-east and S. 30° E.; these occupy, with the short sandy intervals, about 1,000 yards of the shore, and after an interval of sand there appear dark mica-schists interbedded with white limestones. The less micaceous schists have much the same appearance as the cordierite-hornfels without "spots" near the granite contact in the Cape Peninsula, but when seen in thin section under the microscope they are found to be different from the latter. They contain calcite in considerable amount, and effervesce freely with dilute acid. Under the microscope (2728) a slice from this rock shows no trace of the shape of the original grains; it is made of small interlocking areas of quartz, felspar, a very pale biotite (colourless to brownish-green over the polarizer) which is almost or quite uniaxial, a small amount of muscovite, grains of apatite and zircon, rutile needles enclosed in the biotite, an epidote-zoisite mineral, and calcite. Cordierite could not be recognised, nor were any lime-silicate minerals seen. The calcite is intimately associated with the other minerals, which are quite fresh, and is certainly not a recently introduced component. The felspars are microcline and a plagioclase, probably albite, because its refractive index is less than that of quartz and the extinction angles are low.

An abundant rock here is a dark, very fine-grained micaceous schist in which the parallel structure is feebly developed considering that the mica is abundant. Under the microscope (2739) a thin section of this rock is seen to be chiefly made of biotite and felspar. The biotite is practically uniaxial and very strongly pleochroic, pale yellow to deep greenish-brown; the flakes lie in all directions. Other coloured minerals are very scarce, a few grains of magnetite partly hydrated, a single minute crystal of blue tourmaline, and some yellowish granular material which has resulted from the alteration of the biotite. Felspar is very abundant; the greater part is microcline, and there is also a felspar which is often quite untwinned but occasionally has a single twin plane; the refractive index is less than that of quartz, small inclusions of which are found in it as well as in the microcline, so it is probably orthoclase. Quartz is only seen in the form of these small inclusions. A few small flakes of muscovite and grains of apatite are present. No cordierite could be found, nor where "spots" seen in this or any other rock in the district. In the hand-specimens and

outcrops this mica-schist is very like some of the altered Malmesbury beds of the south-western districts, though in the latter (except in Worcester and Robertson) spotted schists or hornfels are commonly found near the granite contacts.

There is much mica-schist with well-developed schistosity owing to the parallel position of the very abundant white mica-flakes. This rock has the appearance of ottrelite-schist owing to the presence of small crystals of biotite scattered at random through it, so that their cleavage faces are often seen on a transverse fracture. There is, however, no ottrelite in the rock. In thin section (2740 and 2741) the chief constituents are seen to be white mica and quartz, the white mica is all lying in one direction; the smaller amount of biotite, a kind similar to that just described, is in much larger individuals scattered through the rock. Magnetite is fairly abundant. The large biotites enclose flakes of white mica, magnetite and quartz grains. Felspar occurs in occasional small round "eyes" enclosing white mica, biotite, magnetite and quartz. It is usually untwinned orthoclase, but towards the periphery of many eyes the microcline structure is developed, and in some cases the whole area is microcline. A few ill-developed grains of a pale yellowish-brown mineral with fairly high refractive index, moderate birefringence, and slight pleochroism are present, but it is not determined, though it may perhaps be staurolite. This type of rock forms thick bands between the limestones and thin layers, often lenticular and only a few feet long, in them.

The limestones on this part of the shore are white or slightly yellowish and thoroughly crystalline rocks with very little magnesium carbonate. The coarser marbles are made of grains about a twentieth of an inch across. They appear to be similar in all respects to the limestones described below from the Grauwe Duinen shore.

To the north of the mouth of Salt River the mica-schists and limestones as a whole dip southwards or south-south-east towards the arkose and quartzites near the mouth, and to the south of the mouth the most frequent direction of dip is north-westerly; so there seems to be a shallow synclinal arrangement here, the axis of which coincides roughly with the course of the Salt River near its mouth. The beds are, however, much disturbed, and little weight can be given to the apparent stratigraphical position of the arkose and quartzite near the mouth.

To the south of the river mouth there are considerable thicknesses of limestone exposed at intervals along the shore, with occasional intercalations of mica-schist. White marble is the

only rock seen cropping out over one stretch of about a mile and a half, though there are frequent intervals of white sand between the outcrops. In thin section (2735, 2736) the marbles are seen to be made of closely-fitting grains of calcite (they stain readily in Lemberg's solution) containing some very minute opaque grains ; when the rock is grey these grains are more abundant than elsewhere.

Search was made in these limestones for varieties containing lime-silicates, but no such rocks were found, though, as mentioned above, thin intercalations of mica-schist containing felspar often occur. This absence of various silicates of lime, magnesia or alumina, such as wollastonite, scapolite, pyroxenes, amphiboles and olivine, is also apparently characteristic of the metamorphosed limestones of the Malmesbury beds in the south-west of the Cape Province, and in this respect the Malmesbury beds which have been invaded by granite and gneiss offer a great contrast to the older limestones of Namaqualand, and those of Kenhardt and Prieska (Marydale beds).

No definite figure can be given as the maximum thickness of the Malmesbury series in the country examined last year. On Byzondermeid, where there is an apparently unbroken succession from the Nieuwerust beds to the Ibiquas conglomerates, there are some 3,000 feet of Malmesbury beds, but the unconformity there is probably at a lower horizon than it is in the middle of Knegt's Vlakte near the Geelbeks River. The maximum thickness is likely to be much more than 3,000 feet.

*The Ibiquas series.*

In previous reports[1] the unconformity between the Ibiquas series and the Malmesbury was recognised chiefly through the occurrence of conglomerates at the base of the Ibiquas containing boulders, which may well have been derived from the Malmesbury beds, and boulders of granite and gneiss supposed to have come from rocks which were intruded in the Malmesbury. At that time the existence of two great granite intrusions in Van Rhyn's Dorp and Namaqualand was not known, and the proofs of their presence makes the evidence from the granite boulders uncertain ; and the discovery of limestones older than the Malmesbury series renders the evidence of the limestone boulders uncertain also, for though the older limestones seen in Namaqualand up to the present

[1] Ann. Rep. Geol. Com. for 1900, pp. 25-29 ; for 1904, pp. 32-35.

time contain lime-silicates foreign to the Malmesbury beds, there may also be some free from such minerals, as in the case of the Wilgenhout Drift and some of the Marydale limestones in Kenhardt.

On the farm Byzondermeid some 3,000 feet of Malmesbury beds lie below the Ibiquas conglomerate, but from near the Byzondermeid—Flennies Kraal boundary (at the water-hole of Eland's Hoorn), where these conglomerates are again seen, south-eastwards to Vliegemuis Gat, they cut obliquely across the Malmesbury beds, and are last seen very near the Nieuwerust outcrops, probably resting on the Nieuwerust beds there and under the sand and gravel of Dorst Vlakte.

East of Rietje, a small water on the north-western part of Byzondermeid, there is a hill capped by the lower part of the Ibiquas beds, on the south-west side of the Byzondermeid fault. The unconformity with the Malmesbury below is scarcely discernible on the hill sides because the two groups have similar dips. The structure is that of a shallow syncline. The Ibiquas conglomerate and grits make a prominent cliff near the top of the hill. The pebbles are often closely packed; vein quartz is the most abundant, grey and greenish quartzites, slates, porphyritic gneiss and a quartz-felspar porphyry also occur. Limestone pebbles were not seen, though the conglomerates at Geelbeks River, Vuur Fontein Extension and other localities to the south contain them.

Between Flennies Kraal and the Spitz Berg hills the Ibiquas beds must come into contact with the Malmesbury beds along the Lang Dam fault, but in a traverse of that area there is no marked change in the neighbourhood of the fault's position. Fragments of slaty rocks and vein quartz, with occasional small exposures of slates, are seen.

In the small outcrops on the veld the dip cannot be made out; the cleavage gives the outcrops the appearance of having high dips, but in the sections large enough to show dip, the cleavage is always steeply inclined but the beds lie at low angles and do not have a constant dip; in several cases they are flat.

The Ibiquas beds must occupy a large part of Knegt's Vlakte, where the superficial deposits conceal them more or less in the wide valleys, but the details have not been worked out owing to scarcity of water.

*The Correlation with the Nama System of German South-West Africa.*[1]

When it became clear that the stratigraphy of the pre-Cape sedimentary rocks of Van Rhyn's Dorp adopted in the Report for 1904 was wrong, and that the true succession was the one described above, a group name for at least the Nieuwerust and Malmesbury series, if not for those and the Ibiquas series, had to be found. As each of the three series is fairly well defined and independent of the other two, although the Nieuwerust—Malmesbury limit may not be drawn at the same horizon throughout the area, any one of them could not be expanded to include the whole group without inconvenience. The term Steinkopf series used by Mr. Leipoldt[2] might prove useful if defined as including both Nieuwerust and Malmesbury beds, but if extended to cover the Ibiquas as well it would only become a synonym for Nama formation, as that term (Schenck's)[3] is used by Range,[4] Lotz[5] and Wagner,[6] who have described the geology of the German territory in recent years. The Nama formation in the southern part of German territory is divided by Dr. Range as follows :—

| | |
|---|---|
| Upper Nama | Fish River beds (Sandstones and shales).<br>Schwarzrand beds (Sandstones and shales). |
| Lower Nama | " Schwarz Kalk " (Dolomites and shales).<br>Kuibis beds (Shales, sandstones and thick quartzites).<br>Basal beds (Arkoses and conglomerates). |

The Basal beds and Kuibis beds together (900 feet) appear from the descriptions to correspond with the Nieuwerust series, and the Schwarz Kalk (600 feet) with the lower part of the Malmesbury ; the Schwarzrand and Fish River beds remain, and may represent the rest of the Malmesbury and the Ibiquas, but they cannot be correlated in detail as yet. There is an overlap or unconformity at the base of the Fish River beds, for they rest on the pre-Nama gneiss in the Waterberg. In the northern part of the territory the Schwarz Kalk is represented by the Otavi dolomites and cherts, which are unconformably overlain by the Fish River beds. The descriptions contained in the papers of the above-mentioned

---

[1] This question is dealt with in a paper entitled " The Nama System in the Cape Province," read before the Geol. Soc. S.A. in April, 1912.

[2] J. G. W. Leipoldt, Trans. Geol. Soc. S.A., xiv., p. 20.

[3] Schenck, Sitzungsberichte d. Niederrhein. Ges. in Bonn, 1885, p. 140 ; " Das Deutsche Kolonialreich," edited by Hans Meyer, Vol. II., 1910.

[4] Range, Monatsberichten der Deuschen Geol. Ges., vol. 61, No. 2 and No. 6 ; ditto, vol. 62, No. 7 ; and Trans. Geol. Soc. S.A., vol. xiii., p. 1.

[5] Lotz, Zeitschrift d. Deutsch. Geol. Ges., vol. 58, 1906, 239.

[6] Wagner, Trans. Geol. Soc. S.A., vol. xiii., p. 107.

geologists show that there is considerable variation in the details of the succession, just as there is in the Nieuwerust—Malmesbury—Ibiquas succession in Van Rhyn's Dorp, the most important being due to the unconformity at the base of the Fish River and Ibiquas series respectively.

An important connecting link between the two areas is furnished by Wyley's account[1] of the beds resting on gneiss on the south side of the Orange River, where there are some hundreds of feet of sandstone or quartzite followed by dark shales and limestones capped by sandstones and shales.

It seems clear that the extension of the term Nama formation or system to the Cape Province is justifiable, and that that name is the best one for the Nieuwerust—Malmesbury—Ibiquas succession.

The geologists quoted above on the stratigraphy of German territory have all suggested that the Nama formation is the western representative of the Transvaal system, a suggestion which Dr. Passarge also advanced in "Die Kalahari." This correlation, which may well prove to be justifiable, is not yet sufficiently warranted to be applicable to the Van Rhyn's Dorp area.

In his paper on Hereroland (1910) Dr. Range describes a locality where the Schwarz Kalk is metamorphosed by granite, an observation which proves that in German territory as in Van Rhyn's Dorp there are granitic intrusions of two ages, one pre-Nama and the other at least post-Malmesbury.

## The Younger Granite and Gneiss.

The facts summarized in the introductory section of this Report prove that in Namaqualand and Van Rhyn's Dorp there is gneiss older than the Nama system and another intrusion of granite and gneiss younger than the Malmesbury series. This younger gneiss has not been found in contact with the Ibiquas beds, and the granite and gneiss pebbles in the latter have not been collected and examined sufficiently to settle their origin.

During the past year's work the only outcrops of the younger granites and gneiss which were seen are those in the Salt River valley and on the coast of Karoetjes Kop and Grauwe Duinen. The gneiss and pegmatites seen in the Malmesbury beds of Salt River valley are deeply weathered; the gneiss is often difficult to distinguish from the schists, but it forms many layers a few feet thick. The largest body seen is a coarse pegmatitic rock with garnets (as much as two inches wide)

[1] Report on Namaqualand, G. 36, 1857, p. 5.

forming a vein 15 feet thick at the water-hole of Graf Water in the Salt River valley on the north-eastern border of Karoetjes Kop. The pegmatites have often been broken by shearing.

The red gneissose granite lying between the conglomerates and the schists to the north of the Salt River mouth is the only one which has been cut for the microscope (2737). It consists of quartz, microcline, muscovite, and a very little greenish biotite containing a few rutile needles. Two rocks, collected and cut in 1904, from the granite near the Malmesbury beds on Klip Drift Extension are certainly from the newer intrusion. They came from the southern edge of the Moed Verloren granitic gneiss. One of them (1232) consists of quartz, microcline, orthoclase, muscovite, a little greenish biotite without rutile, and some magnetite. The other rock which has been cut (1236) consists of quartz, microcline, orthoclase, a single grain of microperthite, in which the second felspar is in very small and not numerous intercalations, brown biotite and a little muscovite; intergrowths of quartz and felspar are frequent. On the Grauwe Duinen shore some banded grey granulites are enclosed by what is presumably part of the newer granite.[1] The specimen which was sliced (1256) consists of quartz, microcline, orthoclase, oligoclase, biotite and muscovite.

The number of available specimens on which to base a comparison of the older and newer granites and gneiss is too small to be of use, but it seems clear that there is no distinction which could be serviceable in the field. It is impossible to judge at the present time whether the apparent greater abundance of perthitic felspars in the older gneiss is of importance.

From the fact that intrusive contacts with the Malmesbury beds have only been seen round the Moed Verloren hills and on the coast, while the Nieuwerust and Malmesbury beds north and north-east of those hills show no sign of contact metamorphism, but where undisturbed junctions are seen there is clear evidence that the Nieuwerust beds lie on an old surface of gneiss, it would appear that the newer intrusions in this region are confined to the south-west. They may have risen along this part of the unconformity between the Nama system and the older gneiss and schists.

In Sheet 19 (Nieuwerust) of the Geological Map of the Cape Province a boundary line between the two intrusions had to be put in for the purpose of indicating the existence of the two intrusions, but its position on the map is arbitrary.

[1] Ann. Rep. for 1904, p. 27.

It is unfortunate that the age of the later intrusion with regard to the Ibiquas series has not been settled. The Ibiquas beds are not known to crop out near the newer granite, and no trace of the latter has been found in the Knegt's Vlakte. The facts that the Ibiquas beds have been much disturbed by faults and by shearing in the western part of the area occupied by them, and that the newer granite has also been much affected by shearing, as seen in the Karoetjes Kop and Salt River outcrops, make it likely that the whole of the shearing effects in the region were produced after the intrusion of the granite, which may be either younger or older than the Ibiquas.

### *Acid Dykes.*

Four dykes of acid rock were found traversing the old gneiss or the Nama system.

A quartz-porphyry dyke 15 feet wide is crossed by Brak River on the east side of Strand Fontein, very near the Klip Vley boundary. It has a grey matrix with many crystals of pink orthoclase, smaller crystals of quartz and green spots in it. Under the microscope (2723) the quartz crystals are seen to be deeply corroded in most instances; the single orthoclase crystal included in the slice is very cloudy with alteration products; the matrix is not micropegmatitic but of the microgranitic type. The green spots are due to patches of epidote and chlorite, which are not confined to the spots but are more abundant there than elsewhere. Along the short part of its course which is visible the dyke trends E. 30° S.

A grey quartz porphyry dyke makes a few outcrops on Kogel Fontein, and lies nearly in the position that the Louis Fontein dyke would occupy if continued to the west-north-west, but it has different characters. In thin section (2747) small quartz crystals, orthoclase, and an acid plagioclase, probably oligoclase, are set in a very fine grained granulitic mosaic of quartz, felspar, green hornblende and magnetite. Both the hornblende and magnetite tend to have idiomorphic outlines.

A quartz-porphyry dyke 12 feet wide with E.—W. course, joined by a second with E. 30° S. course, traverses the marble on the Grauwe Duinen shore; a length of a few feet only is seen. In section (2729) corroded quartz and orthoclase crystals are seen in a microgranitic matrix of quartz and felspar. The matrix in the immediate vicinity of the quartz crystals is richer in quartz than the rest. Small patches of calcite granules are scattered through the rock.

A small dyke five feet thick traverses the marble on the south-west side of the cove on Grauwe Duinen. It has no porphyritic crystals (2752) but consists of quartz and felspar with very small flakes of red-brown biotite and magnetite. The felspars are acid plagioclase and have a tendency towards lath-shaped forms. Calcite has come into the rock, often in minute grains in elongated clusters as if they replaced some thin prismatic crystals.

*Basic dykes.*

In the Report for 1904, p. 32, a peculiar dyke rock with 39·5% of silica was described from the Salt River just below the confluence of the Klein Goerap River; its relationship to rocks of other countries was not recognised, and the same type had not been met with elsewhere in this country. It was subsequently referred to as a camptonite,[1] but it is more like the monchiquites on account of the very small amount of felspar present. A second visit was paid to the locality last year. There are three dykes exposed just above the level of the water in a large pool in the river bed; in the banks above the rock is much decomposed and it could not be traced across the ground at the top. The course of the dykes is W. 20° S.; the northernmost is the thickest, from three to four feet, and each of the others is about 18 inches thick. They are remarkable in containing many small pieces of gneiss. Two sections (2724, 2725) were cut from the new specimens, but few new features are seen in them; the matrix consists of a glass base with grains of calcite, augite, magnetite and minute flakes of red biotite, and it encloses titaniferous augite, olivines replaced by calcite, serpentine and magnetite, and circular patches of an isotropic substance (perhaps analcime) and calcite. The reason why the isotropic base is considered to be glass, and the patches analcime, is that the index of refraction of the patches appear to be distinctly lower than that of the glass, for the surface can be seen. No felspar was detected. Some large augites contain cores in which very much magnetite, biotite and glass are mixed with the augite substance.

In the neighbourhood of the monchiquite there were found nine dykes of a grey or reddish felspathic-looking rock traversing the granite and Malmesbury beds. Some of them contain a few small orthoclase crystals about a tenth of an inch in length. Several of the rocks have a peculiar silky look on a fresh surface, an appearance said to characterise bostonites in which the felspars are arranged as in flow-structure.[2] The

[1] A. L. du Toit, Proc. Geo. Soc. S.A., p. xliii., vol. xiii.
[2] Rosenbusch, "Elemente der Gesteinslehre," 1910, p. 270.

silky-looking rock appears to be weathered, but in thin section (2727) the chief component, felspar, is fresh though cloudy with minute dusty inclusions which have no appreciable effect on polarized light. A very little interstitial quartz is present, and there are small patches of rusty-brown iron oxides and a very little yellowish chloritic material, but no original ferro-magnesian silicates are to be seen nor any sign of pseudomorphs after them. The chief component is a peculiar sort of felspar in ill-defined lath-shaped sections closely packed together. The index of refraction is less than that of quartz. In the larger crystals one twin plane is usually seen ; in many of the small ones an indefinite multiple twinning occurs. In general character this felspar rock resembles descriptions of bostonites. A section through a more stony-looking dyke rock (2726), of which the sp. gr. is 2·78, shows that it is chiefly made of stumpy felspar crystals with irregular boundaries ; a small amount of interstitial quartz, a very little magnetite and some minute yellowish chloritic flakes are also present. The felspar is cloudy, but the particles which give it that appearance have no effect on polarized light but seem to be opaque. The felspar has a lower index of refraction than quartz. It is either untwinned or twinned once only in a rather indefinite manner. This rock seems to be a bostonite or quartz-bostonite. An analysis made by Mr. J. G. Rose shows that there is 4·00% of $K_2O$ and 4·96% of $Na_2O$ present in this rock, amounts which are in agreement with the rock being placed with the bostonites.

On the south-western side of a small cove on the Grauwe Duinen coast there is a mass of dark bluish gabbro-like rock lying between white marble and pebbly quartzite (see Fig. 7). No outcrops have been seen beyond those shown in the figure, and those are in great part covered at high tide. The greatest width of the outcrop is about 150 feet, but its texture is much coarser than that seen in dykes of dolerite of the Karroo type of the same or greater width. It cuts through the bedding planes of the marble and runs parallel to the strike of the latter. The sea has worn a passage some eight feet deep between the two rocks, but at the outer and inner ends of the exposures the two are in contact, but the rock is so weathered and covered with weeds and animals that a clean exposure could not be laid bare. The rock varies in composition slightly owing to the presence of interstitial micropegmatite. Several sections were cut from these outcrops, but they all show great alteration. The chief constituent is labradorite in fairly large crystals ; augite with fine striations parallel to the base is only seen in remnants amongst green chloritic minerals and

calcite; it used to form irregularly-developed crystals, not ophitic masses enclosing felspar; a little brownish biotite and much ilmenite or magnetite are present, and also in some slices a little micropegmatite of quartz and felspar.

This rock is evidently much older than the Karroo dolerites, judging from the great changes it has undergone, and it is free from the ophitic structure which is invariably found in the coarser dolerites of the Karroo.

A curious case of an apparently broken dyke occurs on the shore of Grauwe Duinen and is illustrated in Fig. 8. The dyke, which is less than three feet wide, traverses gneiss, quartz-

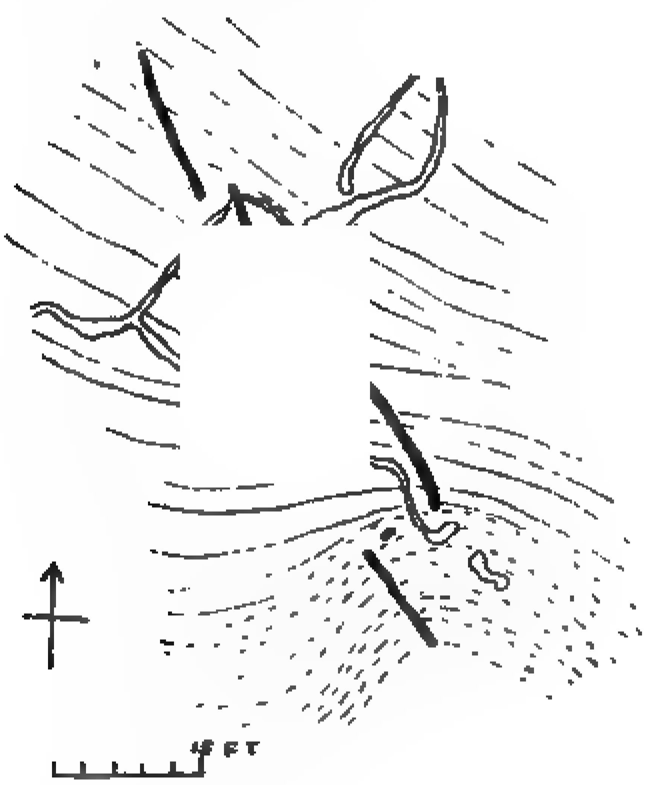


FIG. 8.—Plan of a dyke traversing gneiss (above) and quartz-schist (below on south), and a vein of quartz. Grauwe Duinen shore.

schist and a vein of quartz. No slickensided surfaces or fault cracks connect the ends of the separate portions of the dyke, and the nature of the dyke rock, a fresh dolerite of the type of many thin dykes in the Karroo, rules out the opinion that it has been subjected to any considerable stresses. In thin section (2731) it is seen to consist of small labradorite crystals set in a matrix of granular augite and very small magnetite crystals. The only other constituents are small amygdales of chlorite and a little calcite. The labradorite and augite are quite fresh. It seems certain that the dyke rock followed the interrupted path now laid bare, and that it is not a straight dyke broken by earth-movements subsequently to its intrusion.

A straight dyke five feet thick traverses the pebbly arkose south of the cove where the marble and gabbro occur. The margins are finer grained than the centre, which is alone fresh enough to afford a satisfactory specimen. In section (2730) this rock differs from the Karroo dolerites in having purple augite with strong dispersion, rather like that of the monchiquite of Salt River, though this rock is of a very different type. The purple augite forms small ophitic masses enclosing labradorite crystals. A peculiar feature is the occurrence of a pleochroic brown hornblende at the edges of the augite and often enclosing pieces of the latter, as if the hornblende were the result of alteration of the augite. No olivine or pseudomorphs that can be attributed to it are seen, but there are a few pseudomorphs of a material like bastite together with magnetite and calcite after crystals which may have been enstatite. There is also brown biotite in small flakes, much magnetite and perhaps ilmenite, and calcite and chlorite as alteration products.

A dyke traversing quartz-schist in the gneiss area of the Karoetjes Kop shore consists (2738) of labradorite and purple augite in crystals, and very small brown mica flakes set in a matrix of alteration products, calcite and chlorite chiefly.

This dyke and the previous one, as well as the gabbro, are more like the pre-Cape intrusions, referred to in the Commission's reports as diabase, than Karroo dolerites.

A rock from a well on the eastern side of Wolve Gat (2705) looks like a Karroo dolerite and has a specific gravity of 3·044. It is a coarse-grained ophitic dolerite without olivine, made of labradorite, augite, a little original green hornblende, red biotite, micropegmatite, apatite, ilmenite, pyrites and alteration products in small amount.

A dyke three feet thick runs E. 10° S. through the gneiss of Buffels Fontein and Kliphoek ; it is steeply inclined towards the south. In section (2710) it is seen to be a glassy dolerite like many small dykes in the Karroo. The glassy base is yellowish to colourless and is partly devitrified ; it contains crystals of labradorite, grains of augite and a fair amount of iron ores, magnetite in part at least.

On Modder Fontein east of Garies two coarse dolerite dykes, one six feet wide and the other varying from 15 feet to 100 feet, traverse the gneiss in a N. 35° W. direction ; the foliation of the gneiss trends a few degrees south of west here. In section (2791) it is seen to be made of colourless augite and labradorite with subophitic structure, a very little original greenish-brown hornblende and some red biotite, iron ores and apatite, a little interstitial quartz but no micropegmatite,

and some chlorite. This may perhaps be a Karroo dolerite, but the ophitic structure is much less developed than in such coarse rocks from the Karroo.

Owing to removal of the Cape and Karroo formations from the area where these different dyke-rocks occur there is no way of determining their ages directly. Some of them are very probably of pre-Cape age (the quartz-gabbro and diabase), others of late Karroo age on account of their resemblance to the Karroo dolerites, while the monchiquite and bostonite may well belong to the cretaceous or post-cretaceous period of igneous activity in the Cape Province which gave rise to the melilite-basalts.

### *The Dwyka series.*

The Dwyka series is the only part of the Karroo system met with in the district visited last year, and a thickness of only 350 feet of it was seen.

On the farm Kobeep on the north-eastern boundary of Van Rhyn's Dorp there are three outliers of tillite and shale on the margin of the gneiss plateau of Bushmanland, and two more lie on the eastern side of the farm.

The common beacon of Kobeep, Kokerbooms Kraal and Daauws stands on a remarkable conical hill called Hartslag Kop, which is made of almost unbedded tillite, about 350 feet thick, lying on a flat surface of gneiss. The only evidence of bedding is given by a few short thin layers of limestone concretions or beds. The hill stands on the edge of the gneiss plateau and is almost bare of vegetation. The runnels due to rain and the pale grey colour of the rock combine with the shape of the hill to give it a resemblance to a great mine-dump, and it is a very conspicuous object from the south and west. It is the only hill of the kind within sight when one stands on its summit, for all the other Dwyka hills are flat-topped. The floor of the Dwyka was found exposed on the western side of the hill for two feet or so, but no scratches were seen on the surface of gneiss from which the tillite had just been removed. Usually the actual junction is concealed under fallen débris round Hartslag Kop and the flat Dwyka hills. Where the base of the Dwyka of Hartslag Kop is exposed there is a layer of tillite from one to two feet thick with a calcareous matrix; pebbles up to five inches in diameter, occasionally showing striated surfaces lie in this limestone matrix. Both in this bottom layer and in the rest of the rock forming the hill the pebbles and boulders are scattered at random through a blue-grey argillaceous and slightly sandy matrix. The largest

boulder seen was a piece of gneiss rather over five feet in length.

The flat-topped outlier on which the beacon common to Kobeep, Kamas and Daauws stands has an undulating surface with semi-detached steep-sided hills on the north and east sides. The flanks are terraced, owing to the presence of layers of harder tillite than the intervening rock. Though only two miles from Hartslag Kop, where no such hard layers exist, these Kamas Kopjes, as they are called, show the layers better than any other hills seen. The hard layers have more quartz in them than the soft layers, and they are lighter in colour, or have a red or yellow colour. They closely resemble the hard Dwyka of the plateau above Ezel Kop Vlakte in Calvinia.[1] These hard layers show traces of bedding, but the pebbles in them are not in layers or closely packed. A thin section (1290) from such a layer on the flat-topped hills of the north-eastern part of Dood Drink shows a matrix of quartz grains, the larger of which are more rounded in outline than the smaller, felspar and zircon, connected by a minutely-crystalline quartzose and sericitic material, parts of which are stained brown by iron oxide; a portion of a pebble of a plagioclase (andesine) rock is also seen in the slice.

The Dood Drink hills are the south-western corner of a large area of Dwyka stretching far to the north-east, and the eastern limit was not looked for Possibly this is part of the main Bushmanland Dwyka outcrop. The thickness of the tillite at the escarpment is about 200 feet, but the floor varies in level by some 50 feet in the seven miles of boundary actually followed. The fluctuation in level to the extent noted was seen within a distance of 200 yards; the tillite evidently fills shallow valleys in the old gneiss.

Two of the outliers on Kobeep are quite thin and make no feature. They are shaly tillite with many pebbles, and their boundaries cannot be found with certainty. They form flat or gently-undulating ground, and though careful search was made on many favourable looking gneiss surfaces near them no definite striations were found.

The gneiss surface between the outliers of tillite is often rather thickly covered with boulders and pebbles of various rocks which have weathered out from the tillite. Many striated and facetted stones were found amongst these as well as amongst the fragments in or on the tillite itself.

The most abundant types of rock forming pebbles in the tillite are varieties of hard sandstone and quartzite, red, grey,

[1] Ann. Rep. Geol. Com. for 1900, p. 44.

white and brown; some of them are argillaceous, and a few are conglomeratic with quartz pebbles in them. Rocks like the Matsap quartzites of the Langeberg and Korannaberg are found amongst them. The pebbles of fine-grained banded argillaceous rocks show very well-preserved striations, and so do the amygdaloidal diabase boulders, though the latter are much less abundant than in the tillite of Kenhardt and Prieska. Mica-schist, granite and gneisses of various kinds are abundant. Grey and red quartz- and felspar-porphyries, very like some porphyries associated with the Koras series along the Orange River in Kenhardt and Gordonia, are occasionally seen. Limestone with layers of chert, like that of the Campbell Rand series, is present and so also are various banded ferruginous jaspers, including the bright red kinds. It was noticed that the quartzites and granites were most abundant in the lower part of the tillite and the cherty limestones and amygdaloidal rocks in the upper.

The spherical and irregularly-shaped calcareous concretions so frequently found in the tillite of the western and southern Karroo are abundant in this district.

The soil on the Dwyka series is brown, and it has a veiy different appearance from that of the red sandy soil on the gneiss.

Surface-limestone or tufa is abundant in the Dwyka country, whereas it is not often seen on the gneiss or Nama formation.

### *Pipes east of Kamiesberg.*

Where the Bushmanland plateau merges with the broken country east of Kamiesberg sixteen pipes, presumably of volcanic nature, were met with. These pipes are only part of a larger group of such vents, for Mr. J. G. W. Leipoldt, who surveyed part of western Bushmanland three years ago, sent pieces of the rocks occupying some of the pipes now referred to, and informed us of their position as well as those of others to the north-east. So far as I know these occurrences of pipes filled mainly with a very basic type of lava (melilite-nepheline-basalts) have not previously been referred to in print, and Mr. Leipoldt was the first to notice them and recognise their nature.

The pipes, of which the positions are marked on the plan (Fig. 9), are surrounded by gneiss. Some of them are conspicuous objects, for they make hills, which may be over 100 feet high, on an otherwise rather featureless country; others again have been cut flat with the surrounding gneiss and are only found if one happens to walk across them, though

some of these were first seen from the tops of hills on account of the dark ground on them. In size they range from 45 yards to about 750 yards in diameter, and they vary considerably in shape. It will be convenient to describe them in a conventional order, starting from the south.

No. I. On the eastern side of Vaal Puts, very near the Kamiebees boundary, there is a roughly circular area about 700 yards in diameter, covered with dark soil and doleritic débris with a few outcrops of dolerite and other rocks foreign

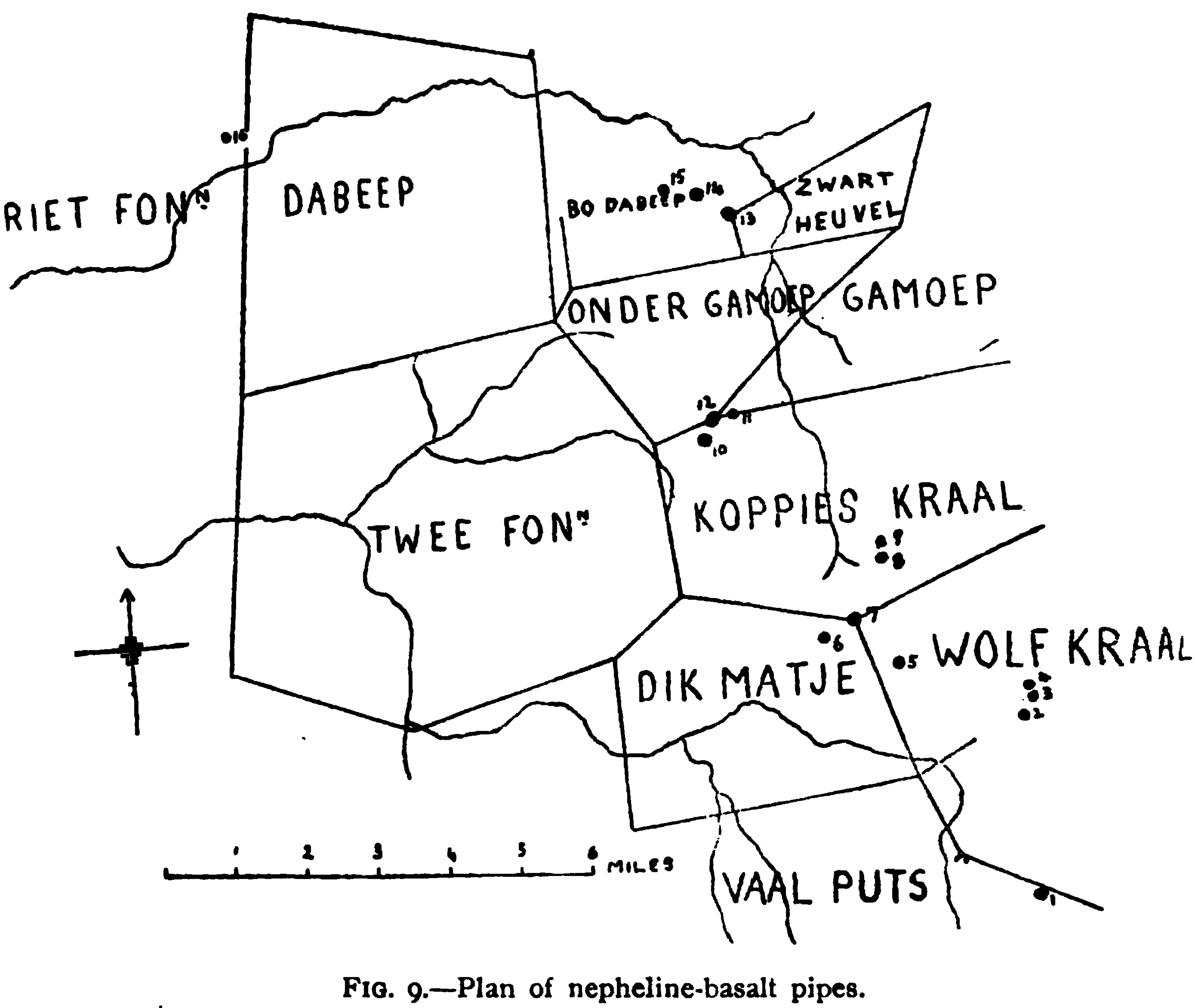



FIG. 9.—Plan of nepheline-basalt pipes.

to the neighbourhood. The surrounding rock is gneiss, but the limits are not clearly defined. No dykes of dolerite were found in the neighbourhood, and as the shape of the doleritic area is that of a pipe it is described here with the rest of the pipes, though the contents are of quite a different nature.

The outcrops of dolerite in the central portion of the area are distinctly coarser than the peripheral outcrops. A specimen of the coarse rock has a specific gravity of 3·01. It has the same general appearance as the dolerites of the Karroo region, but in thin section it shows rather different

characters. In a slice (2823) the rock is seen to be made of augite and plagioclase felspar, with magnetite and a green chloritic mineral in small quantity, orthoclase and also a very little interstitial quartz. There is no olivine or biotite. The augite is a slightly pink variety, and the plagioclase belongs to the andesine-labradorite series; these minerals occur in intergrowths at places, but the augite is usually in long prismatic forms, of which the cross sections show prism and pinacoid faces. The augite occasionally encloses part of a felspar crystal, but ophitic structure is not developed. The magnetite is often seen in rows of crystals with the angles of the octahedra in contact. Outcrops of acid igneous rocks and small pieces of such rocks occur in the dolerite area. Some of these are several feet long. A thin section (2824) cut from a rock looking like a quartz-felspar porphyry (sp. gr. 2·77) with a grey matrix shows corroded quartz and perthitic felspar lying in a very minutely crystalline base, in which there are small and partly skeleton crystals of a plagioclase felspar, probably oligoclase. Some remains of augite crystals are preserved, but this mineral is considerably altered to an aggregate of minute green flakes, perhaps a form of mica, for they seem to extinguish straight. The green mineral is also scattered plentifully through the matrix. Another rock enclosed by the dolerite has a pale matrix (2825) with crystals of orthoclase and quartz; the latter are milky in appearance and deeply corroded. The matrix is seen under the microscope to be made of felspars crowded together and without definite shape, often forming radial bunches, and the substance is cloudy. There is also much green matter in minute flakes and granules.

Quartz porphyries have not been noticed in the Kamiesberg or the western part of Bushmanland, so it seems that the masses lying in the dolerite must have been carried up with it.

No. 2, 3, 4. To the east of Wolf Kraal house there are three pipes within three-quarters of a mile. They make very slight features on the ground; from a distance they look like old werfs, or kraal sites, on account of the dark brown colour of the soil and outcrops.

The southernmost of the three pipes is elongated in the direction of the foliation strike of the gneiss (see Fig. 10); its boundaries were more closely determined than those of any other pipe examined in the district, for they are not much covered by débris from the pipe itself, as is the case where the nepheline-basalt makes a hill, nor by tufaceous limestone or sand, as is frequently the case where the basalt has been cut

level with the surrounding ground. In most parts of the boundaries of the other pipes it is impossible to determine the position of the contact within ten feet or so, often it cannot be done within as many yards, by observation of the soil and outcrops. Pipe No. 2 is filled with nepheline-basalt. The rock weathers with a thin brown crust. The freshly-exposed rock is dull grey with numerous crystals of olivine scattered through it and a few pieces of ilmenite large enough to be seen by the unaided eye. The olivines reach a length of half an inch, but the small crystals, which alone show faces, are very much more numerous than the larger pieces. This rock, like those forming the bulk of the contents of the other pipes except No. 1, has a distinct resemblance in hand specimens to the melilite-basalt of Spiegel River and Sutherland Commonage, but melilite is only found in thin sections from some of these

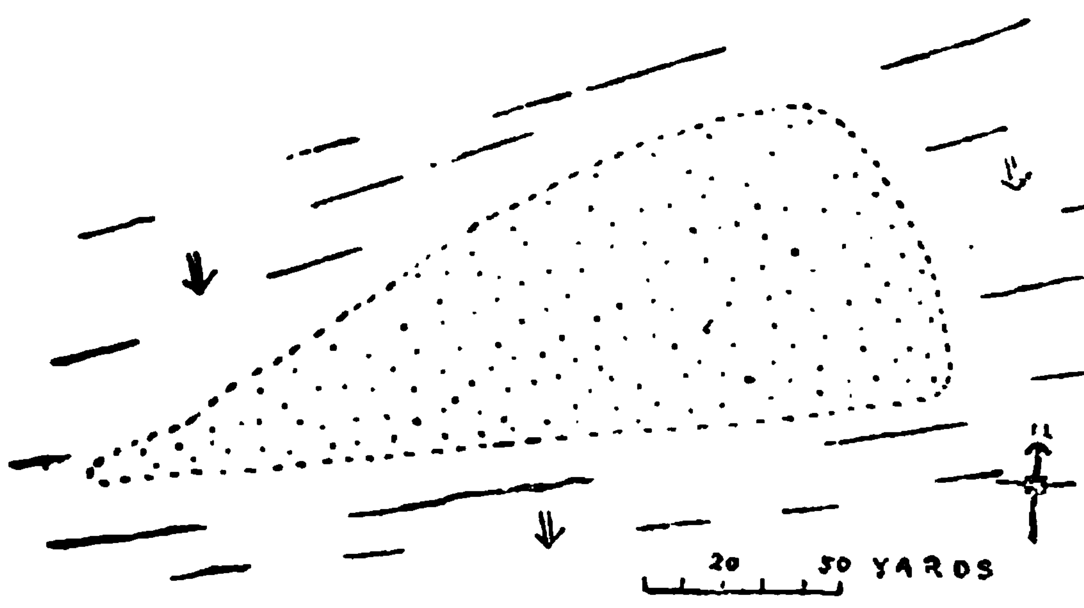


FIG. 10.– Pipe No. 2, on Wolfkraal.

Namaqualand rocks, while nepheline has not been seen in the Sutherland and Spiegel River rocks.

The rock from No. 2 pipe (sp. gr. 3·25) is seen under the microscope (2834) to be made of well-shaped crystals and rounded or angular fragments of olivine lying in a groundmass of small augite prisms, magnetite or titaniferous magnetite, perofskite, nepheline and biotite. The olivine is quite fresh and is usually free from inclusions, but some crystals enclose one or several of the minerals of the groundmass; perofskite and magnetite occur alone in this manner; but the augite, biotite and nepheline occur only in association and evidently fill cavities which were due to irregularity of growth of the olivine. The perofskite and magnetite, in part at least, are of earlier date than the olivine; but the association of augite and other minerals in the enclosures is probably due to their crystallization from portions of the magma caught in the growing olivine. The augites are always of very small size and they are colourless. The perofskite occurs as very small

octahedra and as much larger grains without crystalline form; these larger grains are generally doubly refractive to a slight degree. The biotite is a very pale variety with pleochroism of the normal kind; it plays the part of groundmass, just as the nepheline does, to the augite, magnetite and perofskite. The mineral assigned to nepheline is quite clear and has a low refractive index and low double refraction; cleavages are occasionally found and extinction is parallel to them. In this slice, as in most of the others, the mineral forms quite small interstitial patches, but in a rock from Riet Fontein (pipe No. 16) these areas are larger, and those which remain dark between crossed nicols in plane-polarized light show a distinctly uniaxial figure. Tested in plane-polarized light, and assuming that the best developed cleavage is parallel to the optic axis, the mineral is negative. A solution of the rock in dilute hydrochloric acid, after separation of the iron and silica, gives small cubes on evaporation, presumably chlorides of sodium and potassium, or the former alone. The only silicate in the rock likely to go into solution readily is the clear mineral of the groundmass, and from the results of the tests it is very probably nepheline.

There are a few curious patches enclosed by the nepheline-basalt of this pipe, but patches of the same kind are better seen in some of the other rocks to be described. In this pipe they consist of colourless material, the surface of which is plainly visible, in contrast to that of the nepheline, though the latter has the higher index of refraction according to the results of Becke's test. The mineral is isotropic, and it is probably analcime, the refractive index of which is considerably lower than that of nepheline and balsam. Augite of the same kind that occurs in the groundmass, but in much larger and better developed crystals, is present in these patches.

The rock of pipe No. 3 (sp. gr. 3·23) differs in appearance from that just described in having no very large olivines in it. Under the microscope (2828) it is seen to be a melilite-nepheline-basalt. The olivine crystals reach a length of 1·5 mm. They are of the kind described from No. 2 pipe. The melilite forms the next largest crystals in the rock; ·3 mm. is about the length of the larger individuals. The outline is rather irregular, especially on the basal faces. The single cleavage crack parallel to the base is often seen, and the "peg-structure" is well developed. When the mineral is partly altered it has become granular from the basal faces inwards, between the pegs, so that the latter are unusually conspicuous and the fresh mineral has a very irregular outline. The melilite in this rock is positive in character, and it is uniform in properties

throughout, so that no nucleus of less doubly refracting material is seen. The augite, magnetite, perofskite and nepheline are similar to those in the rock of No. 2 pipe. There is no fresh biotite, but some almost isotropic material in the groundmass may be a pseudomorph after it.

No specimens were taken from pipe No. 9, but the rock resembles that of No. 3 pipe. The nepheline-basalt of these three pipes enclose occasional pieces of gneiss.

On the western side of Wolf Kraal there is a hill of nepheline-basalt, pipe No. 5; the hill rises about 70 feet and has a small beacon at the top. The pipe is elongated in a direction perpendicular to the strike of the foliation in the surrounding

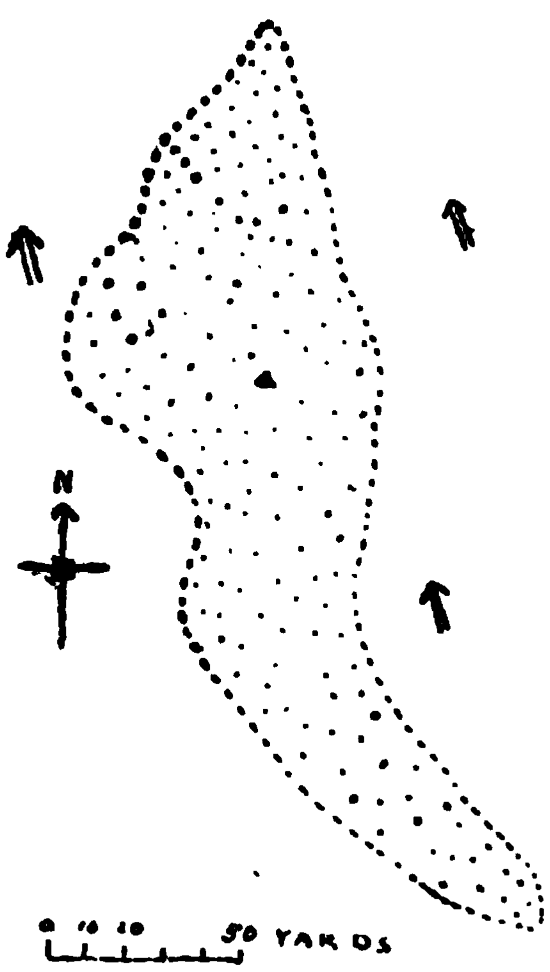



FIG. 11.—Pipe No. 5, Wolfkraal.

gneiss (see Fig. 11). The boundary of the pipe, especially on the western side, is ill-defined, owing to the amount of fragments which have rolled down the slopes of the hill.

The rock is without many large olivines, and lumps of ilmenite are not seen by the unaided eye. In general appearance it is like those described from the other side of Wolf Kraal. The specific gravity of a fresh piece is 3·25. Fragments of gneiss are enclosed by the nepheline-basalt; they are small and scattered at wide intervals through the rock. Under the microscope (2827) crystals of olivine up to a tenth of an inch long are seen scattered through a fine-grained matrix. The olivines usually have crystal faces; they contain very few inclusions and are in places altered to serpentine; magnetite or other forms of iron oxide are very rarely seen

in the serpentine, though in one case minute opaque grains occur in that mineral and appear to have separated out from the olivine. The olivine would seem to be a variety with less iron in it than, for instance, the olivine of the Karroo dolerites. The matrix is made of small augites, perofskite, magnetite, biotite and nepheline. A very few larger grains of augite are present, and these are of a variety with strong dispersion, so that in using ordinary light with the polarizing microscope perfect extinction is not attained, a character said to be found in augite with much titanium in it. The small augites have not got this character. The other minerals occur as in the rocks previously described; the nepheline is present in small quantity only.

Pipe No. 6, on the farm Dik Matje, is about 130 yards in diameter and roughly circular in outline. It forms a low hill. The rock has a vesicular appearance on the outcrop owing to the weathering out of material filling small cavities. Some of these cavities have the shape of steam-holes, but others are irregular and the material in them may have been pseudomorphous after fragments of felspar. The rounded cavities are filled with zeolites, of which natrolite is one. Fragments of gneiss are abundant in this pipe; they are as much as three inches in length, but most of them are smaller.

The rock (2830-1-2-3) is a melilite-nepheline-basalt. The melilite crystals reach ·5 mm. in length; they are positive in character and usually have an internal portion with less birefringence than the external zone. Peg-structure is rarely seen in them. They are more abundant in parts of the slices than elsewhere, and are occasionally arranged with their longest axes parallel to the longest axis of the olivines; thus the olivine and melilite give a parallel structure to the rock, but the smaller constituents do not conform to it. The constituents of the ground mass, perofskite, magnetite, biotite, nepheline, are of the same kind as in the previously described rocks. The few rounded patches in the slices which presumably represent the contents of the cavities seen on the outcrop are not so definitely bounded when seen under the microscope as one might expect. Their outer zone is made of an aggregate of augites, some of which project inwards as well formed crystals, but there is some colourless substance with the augite, apparently nepheline. The interior of the patch is made partly of nepheline and partly of natrolite; in some cases there is an isotropic substance also, which looks like analcime. In a few cases there are bunches of pale green needles with grains and crystals of magnetite amongst them. The colourless minerals in these patches give silica jelly when

dilute hydrochloric acid is put on them—as do the melilites and nepheline of the matrix.

The reason why these small patches are probably not amygdales is that the minerals composing them are also those found in the peripheral portions of the inclusions of gneiss. If one of the latter were cut by the section tangentially near its limits, it would present the same appearance as the patches above described. In one of the slices part of an inclusion is seen; the remains of a twinned plagioclase and untwinned felspar and biotite are associated with radiating bunches of a zeolite, which is probably natrolite, and with a greenish, almost isotropic substance; at the edge of the inclusion there is much augite projecting inwards amongst the zeolitic minerals. The biotite of the gneiss is full of minute opaque inclusions, and the rest of the mineral is deep brown and strongly pleochroic.

The peculiar yellow-red biotite of the matrix is more abundant in the neighbourhood of the inclusions than elsewhere, and in one case it occurs in one of the inclusions.

The beacon common to Wolf Kraal, Kopjes Kraal and Dik Matje stands on a conspicuous brown, rounded, smooth-looking hill, rising some 100 feet above the plain. The melilite-nepheline-basalt which forms the hill (pipe No. 7) crops out over a roughly circular area about 200 yards in diameter. A slice (2829) is seen under the microscope to contain little melilite and no biotite, otherwise it is like the melilite-nepheline-basalts described above.

In the middle of the southern part of Kopjes Kraal there is a mass of nepheline-basalt over an area 300 yards long by 200 wide, which has its longer axis in the direction of the foliation of the gneiss. This is pipe No. 8 of the plan. A low hill marks the occurrence. In neither of the two slices (2835-6) cut from this rock is melilite seen. One of them contains numerous small and irregularly shaped areas of pale yellow isotropic glass with minute hair-like bodies in it, and idiomorphic crystals of the peculiar yellow-red biotite and nepheline, two minerals which are allotriomorphic in the basalts usually. Augite prisms also occur in the glass.

A fairly well-marked banding, due to the occurrence of layers with larger and smaller olivines, is seen in loose blocks, but the position of the banded rock in the pipe could not be found. As in all the pipes where there are no steep slopes of basalt, outcrops are very few; the rock occurs mainly in loose blocks two feet in length and less, and of quite irregular shape.

Pipe No. 9, slightly to the east of north of the one just described, is about 130 yards wide, but it makes no hill.

The beacon common to Kopjes Kraal, Gamoep and Onder Gamoep stands on a hill called Bruin Kop, made of nepheline-basalt and rising about 120 feet above the surface of the surrounding gneiss. There are two other pipes in its neighbourhood (see Fig. 12), of which the smaller makes no feature while the larger, No. 10, forms another rounded hill.

The rock from No. 10 pipe has a somewhat different appearance under the microscope (2838) from the slices previously described, owing to the fact that the augite prisms are on the average about twice the usual size and also to the abundance of the peculiar yellow-red biotite, which occurs in large plates enclosing all the other minerals present except nepheline. Its specific gravity is higher than usual, 3·27. Nepheline is

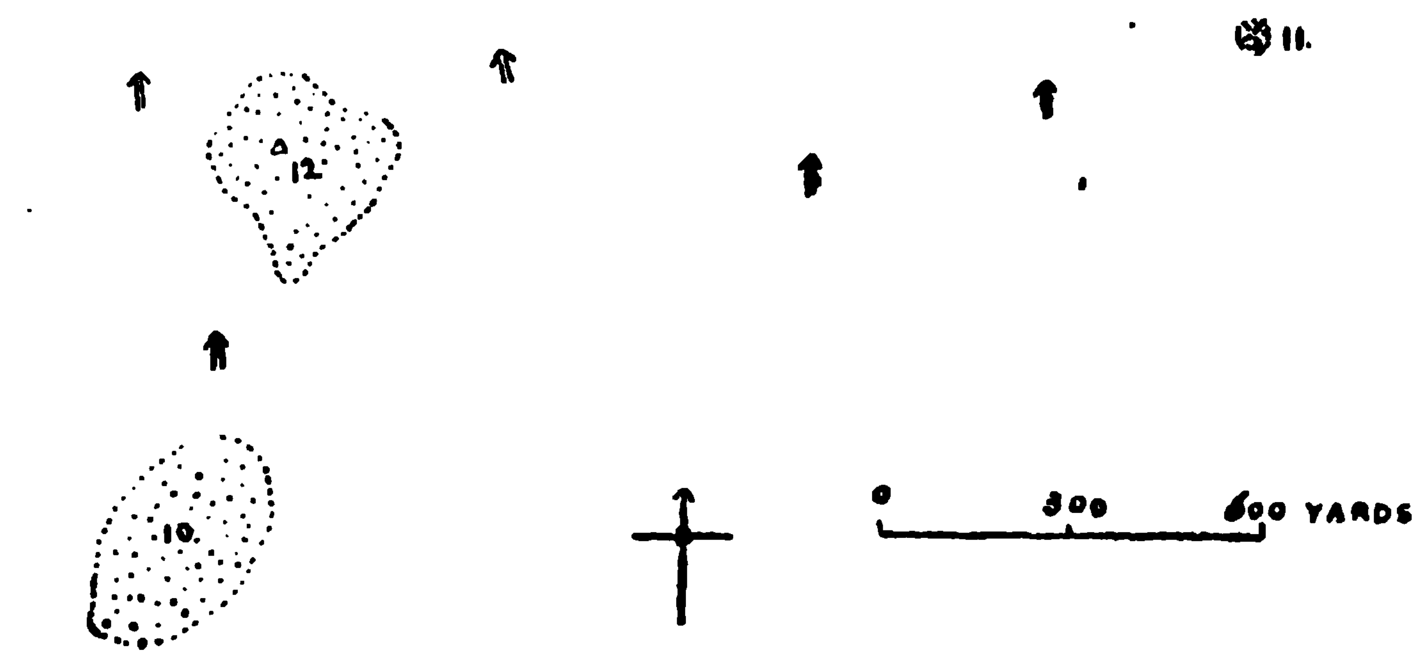



FIG. 12.—Bruin Kop (12) and neighbouring pipes.

fairly abundant, forming the interstitial matter between the other constituents, and at some places patches of nepheline enclosing augite, etc., behave uniformly over a considerable area, just as the biotite does, though the phenomenon is much more easily seen in the case of the biotite on account of that mineral's high birefringence. There are small areas of isotropic and colourless substance, glass or analcime, containing numerous very minute doubly refracting granules. Rounded olivines, as much as an inch in diameter occur in this rock; rounded ilmenites, of much smaller size, are less frequent. The opaque metallic mineral in the thin section of this rock, as in the rest of the nepheline-basalt sections, has either rounded outlines or such that could be derived from octahedra.

The rock of No. 12 pipe is also without melilite but otherwise resembles the Wolf Kraal rocks more than the nepheline-basalt of its neighbour No. 10. It has no biotite in it (2837). Pipe No. 11 is only about 45 yards in diameter and is marked

by a circular patch of brown soil with basalt fragments. The rock has not been examined under the microscope.

The north-west beacon of Zwart Heuvel stands on a hill made by the largest pipe of nepheline-basalt seen in the district. The basalt occurs over an area 750 yards long in S. 30° E. direction and about 300 yards wide. The south-east end of the hill is steep and has excellent outcrops ; on other sides the ground slopes gently to the level of the surrounding gneiss. There is more variety in the rock of this pipe than in any of the other nepheline-basalts yet seen in the district; there is a coarser grained rock than the average forming a group of outcrops over 30 yards long by some 10 feet in width at the top of the steep rise at the south-east end of the hill, and running in a north-easterly direction. With the exception of this coarser rock, the melilite-nepheline-basalt of Zwart Heuvel is similar to several rocks previously described. It contains occasional rounded lumps of ilmenite less than half an inch long, and larger olivines, as well as lumps of olivine-rock up to three inches wide. These lumps are made of many distinct grains of olivine; no other mineral was noticed in them, but they were only examined in the hand-specimens. The ilmenites stand out on the weathered surface of the rock, but the olivines are often weathered out completely.

Seen under the microscope (2842) the rock is found to contain fairly large melilite crystals of positive character and without a core of less birefringent material. No mica was noticed, but in other respects the rock is like those previously described. It is quite fresh ; no serpentine is associated with the olivine.

The coarser rock has portions of different degrees of coarseness in it. The less coarse variety (2843-4) consists of olivine crystals, partly changed to serpentine (without the separation of magnetite) along cracks and round the edges, in a matrix of augite, perofskite, magnetite, apatite, biotite, isotropic and anisotropic matter which includes nepheline. The augites are much larger than usual, reaching a length of over 1·5 mm., and the larger crystals show the effect due to high dispersion. Apatite, which was not identified in the other nepheline-basalts of Namaqualand, is rather abundant. The biotite is of the yellow-red kind with normal pleochroism and forms patches enclosing the other constituents as described in the rock from No. 10 pipe. There is a fair amount of nepheline. The isotropic substance resembles that put down as glass or analcime in the rock from No. 10 pipe. No melilite is seen in these slices.

The coarsest rock met with has much the same appearance in hand-specimens as the one just described, and seems to be indistinguishable from it in the field, but under the microscope (2845-6) it differs greatly from it by the absence of olivine, and the abundance of apatite and natrolite. Though there is much green serpentinous mineral, this has not got the form of olivine crystals, nor does it enclose remnants of olivine; it cannot be regarded as an alteration product of that mineral, but its origin is not clear. Augite forms large prisms enclosing perofskite and magnetite; it is a titaniferous variety with strong dispersion. The biotite, of the same yellow-red colour as in the rocks described above, is in larger plates than usual and can be seen to have a larger axial angle than biotites usually have. Natrolite in radiating bunches is abundant, and nepheline is also abundant.

To the north-west of Zwart Heuvel there are two pipes which make no features. The first one, No. 14, is about 50 yards in diameter; the second, No. 15, is 200 yards long from east to west and 80 yards wide. In both cases the limits are uncertain, and fragments of the nepheline-basalt are alone seen.

A thin section (2847) from the rock of pipe No. 14 shows it to be a melilite-nepheline-basalt without biotite. In most respects the rock is like the melilite-nepheline-basalts from the Wolf Kraal and other pipes, but the melilite in this rock is yellow, while the melilite in the other rocks has no perceptible colour in the thin sections. This melilite is positive in character and uniform in behaviour between crossed nicols throughout each section. No peg structure is seen. The sections more or less perpendicular to the basal plane often have an irregularly-biconcave shape, a feature less frequently noticed in the melilites from the other pipes. Small augite prisms are enclosed by the melilite.

On the north side of the Daweep River near the eastern boundary of Riet Fontein a conical hill of nepheline-basalt stands in a rather broken country of gneiss. The hill is only about 40 feet high, and is covered with loose blocks of nepheline-basalt, often roughly cubical in shape. The pipe seems to be nearly circular in outline, and is about 70 yards in diameter. In one place a mass of gneiss, 20 feet in length, is enclosed by the basalt; the foliation planes in this block are lying almost perpendicular to those in the surrounding gneiss outside the pipe. The enclosed gneiss is friable and weathered, in contrast to the very fresh nepheline-basalt.

Under the microscope (2848) the nepheline-basalt[1] is seen to be without melilite; the olivines are smaller than usual. but the augites are larger than in most of the rocks described above. Nepheline is abundant, but in parts of the slice it has undergone alteration to a fine-grained granular substance. The biotite, magnetite and perofskite have the usual characters seen in the previously described rocks.

It is noteworthy that no dykes of nepheline-basalt or related rocks were seen in the neighbourhood of the pipes or elsewhere in the district examined last year. The monchiquites of Riet Fontein on the Salt River are quite different rocks, though the coarsest rock in the Zwart Heuvel pipe presents some resemblance to them.

The examination of these nepheline-basalts led to the re-examination of the rock collected by Mr. Walker at Tonteldoos Fontein in Sutherland and described in the Annual Report for 1910, p. 62. The colourless material forming the matrix of the olivine, augite, biotite, perofskite and magnetite of that rock is identical in character and appearance with the nepheline of the Namaqualand pipes, and it may without hesitation be referred to that mineral. There is a close general resemblance between these Namaqualand rocks and that from Tonteldoos Fontein. This resemblance is of great interest, because the Tonteldoos Fontein rock comes from near the localities (Sutherland, Saltpetre Kop and Matjes Fontein) where the melilite-basalts are associated with breccias closely approaching kimberlite in character. Thus the Namaqualand pipes become indirectly connected with that remarkable phase of igneous activity which affected an immense area in South Africa in Cretaceous or post-Cretaceous times.

Nepheline-basalts do not seem to have been described from South Africa, though they are known in Nigeria and Kamerun (Falconer, Passarge and Esch)[2], and from the East African volcanic region (H. B. Muff, Mügge)[3].

---

[1] Mr. G. C. Scully, B.A., of Victoria College, has kindly made two careful determinations of the alkalies in a piece of the nepheline-basalt from pipe No. 16, Rietfontein, by the Lawrence Smith method. The results are $K_2O$, 1·52 and 1·55 %; $Na_2O$, 6·08 and 5·99 %.

[2] Falconer, "Geology of Northern Nigeria," p. 255. Passarge, Adamaua, p. 384. Esch, Sitz. Ber. Ak. Wiss. Berlin, 1901, p. 277.

[3] Muff, Colonial Office Reports, Miscellaneous, No. 45, p. 30. Mügge, N. J. Beil. Bd., IV., pp. 602-4.

## Superficial Deposits.

### (1) *Surface quartzites and allied rocks.*

Rocks of this type were found in the coast belt, the Knegt's Vlakte and on the extreme western side of Bushmanland, but not in the Kamiesberg.

On the left bank of Salt River about two miles from the mouth a bed of surface-quartzite underlies the sand at a height of 12 feet above the vley. It consists of pale brown quartzite containing occasional pebbles of quartz and quartzite and it passes into a softer rock below within a distance varying from six inches to two feet. The softer rock is a sandy ferruginous stone which is cut out for building purposes. The quartzite passes laterally into a hard rock made of sand and pebbles cemented with brown oxides of iron and a little silica. The quartzite and the ferruginous rock evidently form a layer more or less parallel to the slope of the hill towards the river, not a horizontal layer.

In the neighbourhood of the Green River valley, surface quartzites were found cropping out from below red sand on the supposed Nieuwerust beds on Rondavel. They are grey and brown quartzites containing pebbles of quartz and rocks from the Nieuwerust beds. Another patch rests on the gneiss between the Zwart Doorn River and the valley in which the Oude Dam water lies. The Oude Dam valley is partly filled with a sandy and clayey deposit which is being removed by denudation. In the short ravines made by rain water in the valley sides thicknesses of ten feet of this material are exposed, and at various levels in it irregular layers of quartzite and ferruginous quartzite are laid bare. The lowest outcrop noticed is only three feet above the floor of the valley and is near the middle of it. In places the ferruginous rock is seen lying above the grey quartzite. The rock contains angular pieces of vein quartz up to six inches in length. The transition from quite soft material to quartzite is gradual. The hard layers are irregularly shaped and are not continuous for more than a few feet. In thin section (2722) a fine grained part of the quartzite is seen to be made of quartz grains of all sizes from the smallest up to those a tenth-inch in diameter. They are almost all angular; rounded grains are very rare, but zircon occurs in rounded oval grains. The quartz grains were probably derived from granite or gneiss, for some of them contain very small inclusions of rutile and other minerals. The connecting matter has a dusty appearance owing to the presence of very minute opaque inclusions, and it is partly chalcedonic

silica, especially in the portions bordering the quartz grains, and partly opaline silica.

In the country west of the Louis Fontein hills and between Kogelfontein and Biesjes Fontein there are level terraces and caps of ferruginous material (ferricrete) made of sandy and clayey detritus cemented with iron oxides. The ferricrete does not occur on the tops of the gneiss hills, and if the now separated caps and terraces were joined together they would form a slightly undulating plain at an average level of perhaps 15 feet above the present surface of the ground. The ferricrete is exposed in vertical walls from eight to ten feet high ; it is hard and cavernous above, where the iron oxides are most abundant, and looser below, where it becomes indistinguishable from the soil lying on the gneiss of the neighbourhood. Recognizable fragments of quartz and dull white felspar are abundant in it. There are several small pans in the neighbourhood of the ferricrete outcrops but below their level, as though the pans were due to unequal denudation of the material. Gneiss crops out on the floors of the pans, which contained water about two inches deep in the rainy season last year.

A small patch of surface-quartzite was found on Goud Vley in Knegt's Vlakte. It contains small pieces of vein quartz, and has just the appearance that the surrounding soil would present were it to be cemented by silica.

In the Zout River valley south of Flamink Vlakte, there are thick superficial deposits of loamy and gravelly material deeply cut into by ravines, and in places cemented loosely by gypsum and limestone. In general appearance these deposits resemble those described from the Oude Dam valley, but no surface-quartzite or ferricrete was seen in them.

The largest area over which rocks of the silcrete type appear at short intervals is on the western edge of Bushmanland, extending from Banker[1] in the south to Vaal Puts in the north, a distance of over 21 miles. How far they stretch into Bushmanland is not known, but they do not appear in Kamiesberg or the highly dissected country between Kamiesberg and Kauwgoed Vlakte.

Surface quartzites of the kind described above, which belong to the same type of rock as the surface quartzites found in many parts of the west and south coast districts and less often in the Langeberg region of Bechuanaland, are not abundant in the west of Bushmanland. In this area the rock is mostly an arkose, or an arkose in which the felspar is more or less completely converted into a dull material which is

[1] This is not the same farm as Banker, in Van Rhyn's Dorp, mentioned previously.

perhaps partly kaolin and partly hydrated aluminium sesquioxide. In every case where the underlying gneiss could be seen it was bleached through a thickness of two or three feet (sometimes much more) from its surface, the only dark mineral left unaltered being ilmenite, which seems to be abundant in the gneiss of Banker; the biotite is considerably altered, and in many cases unrecognizable. It is only in the immediate neighbourhood of, or below, the arkose and quartzite that this peculiar bleaching of the gneiss was seen.

About two miles north-west of the house on Banker there is a patch of whitish, chalky-looking rock on the west side of the road to Plat Bakkies. It contains fragments of ilmenite and quartz. The white material is evidently a product of the alteration of felspar. The gneissose granite on which this rock lies is exposed round the patch and at places within it. Careful examination is required to separate the two rocks in the field, for the felspar of the gneiss is converted into dull white matter. A peculiarity in the bleached gneiss at this and other localities where the circumstances are similar is that the rock is quite hard and coherent, so that specimens can be broken off, and thin sections cut, as from a fresh outcrop, but more easily owing to the lesser toughness of the altered felspar. In this respect the bleached gneiss or granite is very different from the usual result of the weathering of such rocks. Ordinary weathered gneiss crops out abundantly in this area; it is, as usual, a more or less crumbly yellowish rock in which the biotite has a rusty appearance, the ilmenite is represented by rusty patches, and in which bright cleavage faces of felspar are conspicuous. The bleached rock differs from this in having no tendency to crumble, in its dead white colour, and in showing no cleavage faces of felspar. It is evident that the change undergone by the felspar is a different one from that caused by present-day weathering. No chemical analysis have been made of the dull white substances, but a rough test by boiling it in sulphuric acid, filtering, and adding ammonia, when a flocculent precipitate is obtained which is easily re-dissolved in acid and re-precipitated by ammonia, shows that some aluminium hydroxide is present, mixed with a larger amount of insoluble material, probably a hydrated silicate such as kaolin. A thin section (2814) of the altered gneiss shows much quartz and ilmenite and a little zircon embedded in a dull, semi-opaque matrix of very fine grained flaky and dusty material which affects polarized light; a peculiar feature is the presence of a few grains of quite fresh microcline and micoperthite in the same matrix and quite sharply bounded by it without any apparent transition. These fresh felspars

are obviously a very small portion of the original amount of felspar. Part of the original mica is represented by a bleached substance which is in parts pleochroic and rather highly doubly refracting. Only the slightest trace of red staining due to oxide of iron is seen round one of the many pieces of ilmenite.

A short distance to the north-east of the small patch just described there is a much larger area, the limits of which have not yet been ascertained; it is at any rate more than two miles long in a north-easterly direction by as much wide. A vertical section of the superficial deposit resting upon bleached gneiss is seen on the sides of a shallow laagte; the thickness of the superficial rock is nine feet in places as seen in the laagte, but the upper surface rises some 20 feet above the laagte within 200 yards of it. The bleached gneiss at the bottom is like that already described in all essential respects. A thin section (2815) shows no ilmenite merely because it was cut from a specimen with very little of that mineral, which is seen in neighbouring portions of the rock; there are no remnants of unaltered felspar, and the biotite is completely bleached; quartz and zircon alone remain, embedded in the semi-opaque matrix. The basal portion of the overlying deposits contain a very large amount of the dull white product of alteration of the felspar and much ilmenite with fragments of vein quartz, but this white rock passes upwards into yellowish loose quartzitic sandstone, and this again into compact glassy-looking quartzite just like the usual surface quartzite of the west and south of the Cape Province. There are numerous cavernous portions with much chalcedonic and opaline silica in irregular patches and lining cavities; and there are other portions of the rock rich in brown oxides of iron. The upper surface of this rock is very irregular and lumpy in form; rounded and jagged outcrops project a foot or less from the sand filling the spaces between them. It is noteworthy that in the vertical sections at this locality no sign of bedding was seen, in marked contrast to some good exposures further north-west on the same farm which will be described below. Sections similar to that described above can be seen at intervals along two or three miles on either side of the laagte.

The conclusion to be drawn from the facts presented above is that for some unknown reason the gneiss lost silica and iron from its felspars and biotite, and that these materials were concentrated in the overlying detritus which has not travelled far, for there are no rounded pebbles or well-rounded grains of sand. A considerable amount of clayey material must

have been entirely removed from the area. The ilmenite appears to be absent from the glassy quartzites, though it is abundant in the underlying looser sandstone. Whether this is the result of the greater specific gravity of the grains of that mineral or of decomposition could not be decided, though the apparent absence of partially-weathered grains makes the former supposition the more probable. The want of analyses prevents a discussion of the fate of the alkalies in the original felspars at the present time.

About two and a half miles west of Banker the road to Kauwgoed Vlakte passes over a circular area of white gneiss like that described above. The area is about 250 yards in diameter, and the white, altered rock is rather sharply separated from the unaltered gneiss round it; the transition takes place within two or three feet. A thin section of the unaltered gneiss nearest the white rock (2817) contains quartz, microcline, microperthite, orthoclase, an acid plagioclase, biotite, apatite and ilmenite. The biotite is partially bleached, and the orthoclase and some of the plagioclase and perthite is cloudy, but the rock is evidently very slightly altered compared to the white rock a few feet away. No superficial deposits are to be seen on this small area.

Four miles further along the road to Kauwgoed Vlakte a strip of superficial deposits about three miles long flanks the western side of a laagte. The beacon common to Kaams, Banker and Kauwgoed Vlakte stands on the northern end of it. In a deep ravine 15 feet of the white altered gneiss are exposed, and on it there are some 25 feet of roughly-bedded white sandstone, parts of which are thoroughly silicified; veins of quartz traverse the white gneiss, and the lower parts of the overlying rock contain many fragments of vein quartz. A thin section (2818) through a portion of the sandstone, which is not highly silicified, shows large numbers of angular grains of quartz and a few rounded ones set in a semi-opaque matrix of the white altered felspathic material; grains of ilmenite are numerous, but in this case several of them are partly changed to a yellow-red opaque substance. A few grains of zircon and flakes of white mica, apparently derived from a granite, are the only other constituents.

Further north than the ravine described there are exposures of 25 feet of white gneiss underlying from 15-20 feet of superficial deposits. In one place the white gneiss and the ordinary reddish gneiss are separated sharply by a foliation plane for several feet; the rock below this plane has not been appreciably affected. The superficial deposits of this part of the strip are strongly false-bedded in the lowest eight feet or so of their

thickness. At the base there is a varying thickness of gravel, rounded quartz pebbles and pebbles of the white gneiss are embedded in a white and black matrix made of quartz grains, ilmenite and the altered felspar; in places chalcedony forms the cement of the grains. False-bedded sandstone lies above the gravel, but the upper part of the section, often 10 feet in height, is either a whitish sandstone or quartzite without definite bedding. The complete cementation by silica has taken place sporadically, often at a distance of a foot or more from the top of the exposed sections. The general appearance of these sections is like that of the Cave Sandstone in Matatiele, and the white gneiss is often hollowed out into shallow caves overhung by the superficial deposits.

A part of the rock seen in these cliffs was undoubtedly deposited in a valley by running water, but the upper portion shows no sign of bedding or layers of pebbles.

The most perplexing occurrence of these peculiar rocks on Banker lies about a mile and a half north-west of the house on the farm; the area covered is about 300 yards long in a north-westerly direction and rather irregular in outline. It has been prospected because opaline silica of an unusual form occurs there, and the following account depends chiefly on an examination of the prospecting holes. The plan of the area in Fig. 13 was made with a compass and by pacing the distances. The crosses indicate the position of outcrops of gneiss and crumbly fragments of gneiss in the soil outside the limits of the area, which cannot be very closely determined on the ground without digging trenches. The boundary of the rocks containing opaline silica cannot be far from the position indicated by the dotted line in Fig. 13, and there is now no connection at the surface between these rocks and the superficial deposits previously described.

At the surface the area is distinguished from the surrounding country directly underlain by gneiss by the absence of outcrops of that rock and by the covering of whitish fine sandy soil in place of the coarse soil on the gneiss, and also by the outcrops marked G, H. Formerly an outcrop existed at A, but a pit has replaced it.

The pit A affords the best view of the rocks within the area. The pit is about eight feet deep, and a short tunnel has been driven westwards to another shallow pit ten feet away. The rock exposed is a clayey felspathic grit containing many pieces of ilmenite up to half an inch long and strings and patches of opaline silica. The rock is in part well bedded in layers from one to four inches thick, continuous and uniform in thickness to the limit of the exposures. These beds dip towards

W. 10° S. at angles of from 35° to 45°, thus in the few feet exposed there is a slight flexuring of the beds. In general appearance these rocks are like the loose sandstones of the superficial deposits described above, but the felspar is only partly changed to the dull white substance; many fragments show bright cleavages. Quartz grains are abundant, and a few pieces of unaltered gneiss two or three inches long were found in the grit. A few small pellets of greenish mudstone, soft and friable, like the rock to be mentioned below from pit E, occur in the grit. Small masses of the grit are impregnated with silica and resemble the silcrete or surface quartzite of the neighbourhood; these masses are not boulders or pebbles but impregnations in place. The opal occurs in

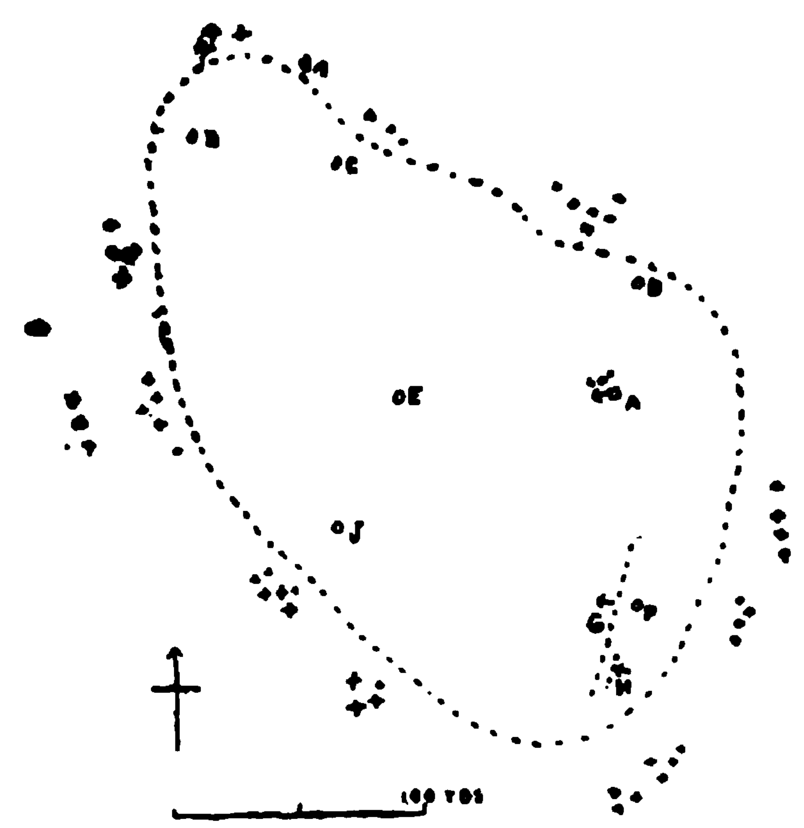


FIG. 13.—Plan of outcrops and pits on Banker.

thin, interrupted layers not more than half an inch thick, in irregularly-shaped lumps, and in cylindrical or tubular form in which traces of wood structure are generally visible; the same structure can be detected in some of the irregularly-shaped masses. It is generally yellowish, grey, brown or whitish in colour, less often it has a green tinge. Specimens with the play of colours that makes some opal valuable have not been found. In a thin section of a specimen which showed wood structure the cell walls are moderately well preserved where the replacing silica is isotropic, *i.e.*, where it is opal; where it is chalcedony the cell walls are barely visible. The specimen is only of value in proving that the silica does to some extent replace woody stems; it will not give evidence as to the genus to which the stems belonged. Some of the silicified stems are two inches in diameter.

The outcrop at G is a hard grit which is traceable for several yards, dipping at a fairly high angle rather to the north of west. It is a pale yellowish rock owing to the colour of the matrix, which contains fragments of quartz, felspar and ilmenite. Under the microscope (2812) the grains are seen to be angular; the felspar (microperthite and microcline) is rather dull. The ilmenite as a rule is in less angular shapes than the quartz and felspar. A few flakes of bleached biotite are present. The groundmass is a semi-opaque whitish material occasionally showing minute scales with low double refraction; it is like the dull white material of the superficial rocks described above. No opal was seen in the outcrops.

The outcrop at H is a thin layer of red, brittle rock flecked with whitish chalcedony and containing many quartz grains. In thin section (2813) the matrix is mostly dull red, semi-opaque material, apparently opal charged with red dusty matter; the pale portions seem to be chalcedony with very fine texture charged with whitish dust. The grains in the siliceous matrix are chiefly quartz and angular in shape; a few grains of rusty ilmenite and of zircon are also present, but there is no felspar. The outcrop has a dip parallel to that of the grit just to the west.

The pit F is only two or three feet deep; it exposes soft grit containing ilmenite.

At E there is a pit about 12 feet deep; the upper seven feet are in soft whitish rock with very little grit, and below this lies green fragile mudstone. These deposits are not bedded, and the passage from one to the other is not sharply marked.

The pit at B is in unbedded sandy felspathic grit containing a few large boulders of partly altered granitic gneiss, lumps of ilmenite and one pebble of dark quartzite coated with a layer of opal a third of an inch thick. There is also an irregular pocket of very soft whitish powder, which is a hydrated aluminous silicate in very minute crystalline scales. The largest granite boulder was three feet in diameter; the felspar is much altered, though in places cleavages are visible; the biotite is bleached, but the ilmenite, which is abundant, is fresh. The boulder is traversed by slickensided surfaces which seem to have been made after the alteration of the rock had taken place. The surfaces are curved and somewhat irregular in form, and several of them lie roughly parallel and close together, one above another. Slickensides of this kind were not seen in the outcrops of fresh rock. In thin section (2810, 2811) the rock of the large boulder is seen to consist of quartz, semi-opaque whitish material replacing felspars, ilmenite and bleached biotite. Fresh felspar is not seen. A

few flakes of biotite entirely enclosed by quartz are unaltered and red in colour. The rest of the biotite is much bleached, the less altered portions being in the middle of the flakes.

The pit C is eight feet deep in a gritty felspathic loose rock containing angular and rounded pieces of fresh gneiss, with irregularly-shaped patches of chalcedony and opal in the gritty rock.

At D there is a shallow pit in white gritty rock containing ilmenite and straggling layers of opal. Bedding is not seen in C or D.

The peculiarities at this locality are the occurrence of fossil wood, the peculiarly coloured opal, the high dip of the layers in the south-eastern part of the area, and the slickensiding of the granite boulder. Whether there is any considerable depth of the deposits here is of course unknown; the deepest pit is only sunk 12 feet. The high dips seen and the slickensided rock point to some kind of disturbance having affected the superficial deposits very locally, and the shape of the group of outcrops makes one suspect that there was at this spot an explosion of volcanic nature which failed to establish a "pipe" of the kind found a few miles further north filled with nepheline-basalt. At the present time no evidence as to the relation between these pipes and the superficial deposits can be brought forward, but it is quite possible that their relative ages can be established in the district.

Two small patches of ordinary surface-quartzite, slightly ferruginous, were seen on Kaams, and another on the western part of Plat Bakkies. Three small patches of surface-quartzite were seen on the western part of Rondegat, in one of which the cement is partly opaline silica.

On the western part of Vaal Puts there are outliers of highly felspathic surface-quartzite from three to six feet thick resting on reddish slightly weathered gneiss. One of them is part of a low ridge which is continued southwards on Vaal Puts. Neither these arkoses or the gneiss they rest on show any signs of the peculiar white product of alteration seen in the Banker outcrops. They are on about the same level as the plateau of Bushmanland.

### (2) *Limestones and gypsum.*

Superficial limestones are not a marked feature in the district traversed last year. None were seen on the coast or in the coastal sand veld corresponding to those of Saldanha Bay and the Bredasdorp coast.

In the West of Bushmanland there are a few small patches occasionally appearing above the soil on Plat Bakkies and

Rondegat. There is no Dwyka in the immediate neighbourhood and the underlying rock is gneiss. The limestone is of the loose tufaceous type and it contains grains of quartz and felspar. This limestone becomes abundant in the Dwyka area.

Surface limestone was not seen in the Kamiesberg, but patches are occasionally met with on the Malmesbury and Ibiquas beds of Knegt's Vlakte and the northern valleys opening into it.

On Stof Kraal the red sandy soil between the hills of gneiss is found to be cemented with gypsum at a depth of a foot or two below the surface, and in a pit the cementation is seen to extend downwards through four feet of the subsoil.

(3) *Sands.*

The soil in all parts of the district outside Knegt's Vlakte becomes sandy where the slope of the ground is very slight, but the accumulations are slight except on the coast belt. The extreme western fringe of Bushmanland was the only part of that country examined last year, and no dunes were met with, though they are said to be formidable obstacles to wheeled traffic further east.

The sand of the coastal belt is felspathic and reddish in colour; only within half a mile or so of the shore does the sand contain little else than quartz, where it has a white colour. For a distance of several miles (up to 17) from the coast the country is covered with red sand, which occasionally forms low dunes partly overgrown with vegetation. Travelling with cart or waggon is heavy work for the animals, but bare shifting dunes are not found except immediately behind the shore. The only conspicuous area of bare sand seen in the district is just to the north of Green River mouth, between the shore and the river where the latter turns southwards. The sand is white and rises some 200 feet from the sandy shore. There seems to be no constant direction taken by the sand dunes; near the shore they are roughly parallel to it, but inland the direction changes considerably. In the country within five miles of the Green River the short dunes partially covered with vegetation, often have a south-westerly trend, but southwards, towards Brak River, north-south and north-north-west trends are more usual.

On the coast there are occasional stretches of grey or almost black sand between the white or pale-coloured stretches. These dark sands are due to the concentration of magnetite and ilmenite grains in certain areas and have no apparent relation to the nature of the rock in the neighbourhood. Garnet

is always abundant in the dark sand, and quartz is the commonest colourless mineral. In a specimen of dark sand from the shore south of Brak River garnet, quartz, zircon and augite were identified.

On the Van Rhyn's Dorp coast peculiar collections of rocks were found on the beach and in a raised beach near Strand Fontein in 1903[1]. The boulders include many rocks not found in the district. No such collections of boulders were found last year, though a few isolated foreign boulders were seen on the shore south of Green River and in the lagoon of that river. One of them is from a fine grained basic volcanic rock made of labradorite or basic andesine laths, rather irregularly formed and usually partly altered crystals of pale purplish augite, small crystals of brown hornblende and magnetite in a groundmass of clacite, chlorite and devitrified glass (2718). The other from which a slice was cut is (2720) an amygdaloidal lava rather like the last but without hornblende. The source of these boulders is not known.

## *Water supplies.*

The water supplies in this area are very poor. There are no streams which run through the year, even within the Kamiesberg, though for various periods, according to the rainfall, the upper courses of Green River and Buffel's River and their tributaries have water every winter. Last year Buffel's River ran from the sources to Spektakel, and Green River as far as Rondavel.

The wells along the Green River valley are shallow and become more and more brak as the time passes since the last heavy rains. It is only in Kamiesberg and in the deep valleys like those of Modder Fontein and Groot Riet that the wells remain fresh.

There are very few springs issuing from the rocks; a small fresh one at Kamaboos has been carefully opened and the water led through pipes to a tank; probably others of this kind in the steep kloofs round the edge of the Bushmanland and Kamiesberg gneiss could be found and treated in a similar way. The rock spring at Zout Fontein on Een Koker is almost too brak for use. Most of the springs issue from superficial deposits in the valleys, and they are more or less brak.

The wells in the gneiss give only brak water, but none deeper than 40 feet was seen.

No dams of any size were seen. The subsoil, except in Knegt's Vlakte, is too porous to allow the usual small dams, such as are frequently made in the Karroo, to be successful.

[1] Ann. Rep. Geol. Com. for 1903, p. 162.

In winter-time many people and their stock are supplied with fresh water from small depressions in the gneiss outcrops. These depressions are of all sizes up to some 30 feet in length in solid gneiss. Their formation can be explained in the following way. At first they are nearly flat surfaces on which a little soil lies ; vegetation grows in this soil after rain and the processes of chemical weathering disintegrate the rock below the soil faster than the bare gneiss round it is removed under the influence of changes of temperature, rain and wind. In droughts these shallow patches of soil may be removed by the wind which then attacks the weathered gneiss below. After rain plants again obtain a footing, and so the process goes on till depressions several feet deep and as much as 30 feet long are formed. These are filled more or less completely by soil until dug out by man. All stages in the production of these water holes can be seen both in the neighbourhood of Kamiesberg and in the coast country, but they are confined to the gneiss and granite ; similar features were not seen on outcrops of any part of the Nama formation.

# GEOLOGICAL SURVEY

OF

# PART OF THE TRANSKEI.

BY

ALEX. L. DU TOIT.

# GEOLOGICAL SURVEY

OF

# PART OF THE TRANSKEI.

---

BY ALEX. L. DU TOIT.

---

The area examined lies to the south-east of the Division of Maclear, the work being carried as far as the sea-coast, thus completing a block of country stretching from the Drakensbergen to the shores of the Indian Ocean. It includes the Divisions of Libode, Ngqeleni, Tsolo and parts of Umtata, Qumbu and Engcobo, as shown on the accompanying small-scale map. The western portion belongs to Tembuland, while the eastern constitutes what is known as Western Pondoland.

With the exception of the two blocks of farms around Umtata and Tsolo respectively, the country is unmapped, and the same method was adopted as during last year, namely, a plane-table survey on the scale of 800 Cape roods to the inch based on the stations of the Secondary Triangulation.

This country was traversed in several directions some years ago by Dr. Rogers and Prof. Schwarz and their notes upon the main geological features of the region are recorded in the Annual Reports for 1901 and 1902. Travelling inland from St. John's one sees the full succession in the Karroo system from the Dwyka boulder-beds at the base up to the basalts of the Drakensbergen, the various divisions dipping north-westwards at an angle of from 1° to 2°. The older strata appear therefore in the east and the younger horizons in the west of the Transkei. (See Fig. 1.)

The present Report deals principally with the Ecca and Beaufort series and with their attendant intrusions of Karroo dolerite. In the coastal belt, however, there is present a monoclinal flexure of great importance, giving rise to a sea-ward dip in the strata and of such magnitude that the lowest sub-division of the Stormberg series—the Molteno beds—are brought down on the coast itself, accompanied by conglomerates of Cretaceous age. This interesting strip of disturbed country will be described by itself later on.

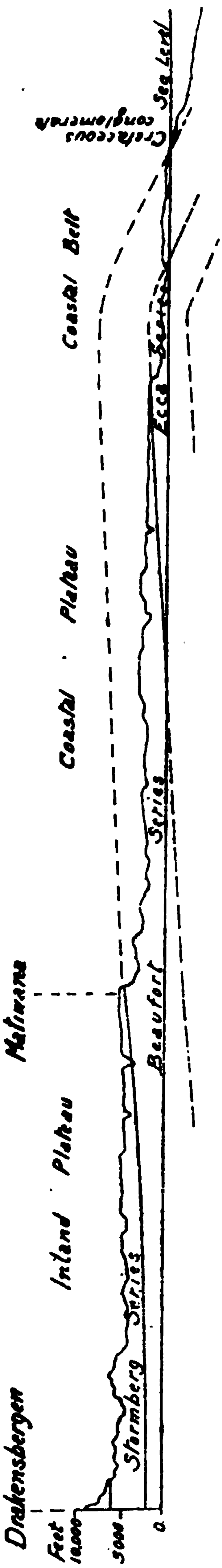



FIG. 1.—Section from the Drakensbergen to the shores of the Indian Ocean at the Umgazana River; length 92 miles.

## PHYSICAL FEATURES.

The area possesses a diversified topography and can be divided into three belts of country which extend parallel to the coast and at different distances from the ocean, each of which is characterised by a distinct type of topography. The first of these is the *Coastal Belt*, a region approximately 15 miles in breadth rising rapidly from sea-level to an altitude a few hundred feet less than the 2,000 foot plateau. It forms heavy country, being intersected by the large rivers which rise at or near the Drakensbergen, while its surface is furrowed by a maze of streams with comparatively short courses. Only rarely does the nature of the formation influence the form of the. ground to any degree ; the outlines of the hills are, speaking generally, of the same rounded and knobbed character whether the underlying rock is dolerite, sandstone or shale, or whether the beds are lying perfectly flat or are tilted. The valleys are generally not particularly steep-sided, except at river bends; sometimes, indeed, they are broad-bottomed with the river meandering from side to side. Many of the smaller depressions terminate in steep heads, which are then almost invariably occupied by a small patch of forest' the vegetation preventing the soil from creeping down the slope and being itself nourished by water escaping at the foot of the ridge. Indeed, in a few cases the angle of slope is greatest at this point, that of the sides being much less. Owing to the high rainfall, more evenly distributed through the year than over the inland region, this section is clothed with tall grass and supports extensive areas of dense forest, as, for example, those at Hluleka, Ebulawa, Qokama and Nomadolo ; indeed, it is

often with great difficulty that the ge
traced satisfactorily in certain localities.
shore is often so rapid as to produce cc
the coast overgrown by wild bananas a
vegetation.

The inner limit of the Coastal Belt is
dolerite escarpment facing seawards and
in plan owing to the maze of deep go
developed by the Umtata, Umtakatyi, Um
and their tributaries. Along the face
and in ravines leading back into the p
forest nestle; waterfalls are not uncom
precipice.

The *Coastal Plateau*, the second of th
sions, forms a belt of rolling country v
30 to 40 miles and possessing an altit
3,500 feet, the general level increasin
surface there rise low ridges, nearly
dolerite, while spurs projecting from th
to the west and forming the divides bet
namely, the Umtata, Tsitsa and Tina
of the feature.

Across this plateau the rivers pass
generally sunk some distance below the
ground. The main road from Umtata
Tsolo and Qumbu follows the easiest ro
angles the course of the drainage with th
and ascent. A route parallel to this
would traverse shallower stream-chan
numerous and difficult ridges, while c
would pass over more even country in
rivers are much more deeply sunk, for
are frequently hemmed in by cliffs hund

The rocks over the flattish portion of t
ally hidden by light sandy soil, whitis
colour and this even where the underl
though more commonly in that case th
blackish or less frequently deep orange
grass covering this part of the Transkei
as in the Coastal Belt, while forests are
a few conspicuous ridges, *e.g.*, the Nq
Forests, but numerous areas of fine i
preserved in the kloofs which indent t
Zuurberg; for instance, the forests a
Baziya, Qelana, Qalibomvu, Sendenko,

A point to be specially noted is the fact that the vegetation is always most profuse on the southerly face of a ridge or in a kloof opening to the southward. The mists and rain-bearing winds come from the south and slopes which face north or valleys opening in that direction are usually devoid of any but scattered trees. Perhaps this peculiarity cannot better be seen than in the neighbourhood of Jenca (Tsolo) where in the case of kloofs leading north-eastwards the one side is bare with numerous outcrops of shales while on the other the rocks are hidden by soil and bush.

The third region is the *Inland Plateau*, known generally as the Zuurberg, which forms the south-easterly limit of the Stormberg series, the edge of the escarpment being composed of the massive coarse grained Indwe sandstone with capping of dolerite, as described in the Annual Reports for 1909 and 1910. The present work merely completes the tracing of the outcrop of this conspicuous member of the Molteno beds.

This plateau, much broken by ravines and gorges, extends inwards to the foot of the Drakensbergen, its outer edge (5,000-5,500 feet) being generally much higher than the narrow belt of less broken country lying at the foot of the Drakensbergen along which the railway from Elliot to Maclear has been carried.

The Transkei may thus be likened to a series of broad steps rising one above the other, the lowest one, however, being more accurately described as a highly diversified slope extending between the edge of the first plateau and the sea coast (see map). The roads follow more or less the course of the watersheds and a few of the routes are perforce somewhat circuitous. In the broken coastal belt the narrowness of the ridges and their sinuous crest-lines has necessitated a good deal of excavation, as for instance along the main road from Libode to St. John's. Many of the branch roads are almost impossible to negociate with a waggon, while to the south of Ngqeleni even the bridle paths are heavy and seldom direct.

## The Ecca Series.

In the report for 1901 the name Umsikaba beds was applied to the strata which immediately overlay the Dwyka boulder beds in Pondoland. In view, however, of the fact that these beds correspond both stratigraphically and lithologically with the Ecca series as mapped in the Northern Karroo the name Ecca series will be used in this report since the other designation becomes no longer necessary.

The Ecca beds of the Ngqeleni and P
consists of from 2,000 to 2,500 feet o
rocks, dark blue or blue-black in colc
overlying arenaceous Beaufort beds.
the map the Ecca beds cover a large
John's, extending far up the narrow
Umzimvubu by reason of their near
Near Old Bunting where the mono
evidence the belt is very much contra
the deep valleys of the Umtakatyi and
Beaufort beds being nearly complete
river (see Fig. 1 and Map).

Over large areas the beds are only we
channels or in road cuttings, for the so
readily break down to give dark soils of
The common manner of weathering
subsoil full of small flakes of pale blue
soil is either deep umber, chocolate, o
deep red, usually clayey in texture, se
Indeed the soils of the Ecca are marke
making the roads heavy in wet weath

The base of the formation was only
namely along the main road from St.
Along the winding ascent from Izin
expose the Dwyka boulder-beds up to
of a mile from the watershed of the Um
deposit and sharply defined from it the
soft carbonaceous shales recalling at
" White-Band " taken as the bounda
and Ecca Series in the Karroo. This
and blue-black shales with a south
gradually flattening in inclination, so
the Umgazi Drift there are nearly hori
which rise on either side to form roun
in height, excellent sections of unwe
afforded by the deep road cuttings.
about Tombo Trading Station there
hard sandstones usually dark grey in c
scales of white mica ; similar hard band
These rocks must not be confused w
have through contact with dolerite been
hard lydiamite, as for instance at the

A conspicuous bed of sandstone mark
of the Ecca series forming fine precip
and Ngqongweni Trading Stations an
waterfalls, especially the one at the

Dokodela River (this name is given to the upper section of the Umgazana) falls about 50 feet into a gorge which deepens rapidly for some distance below this point.

The same prominent grey sandstone forms cliffs along the Umtakatyi, near Ntsundwana and along the Umdumbi at Ntibane Trading Station. It is followed by a thickness of several hundred feet of soft dark blue shales with circular pyritous blotches on the bedding planes, a feature which has been observed by Messrs. Rogers and Schwarz to characterise similar beds in Eastern Pondoland. This uppermost zone of the Ecca series is finely exposed in the road cuttings through the Bomveni Bush, south of Old Bunting, while natural exposures are not uncommon on the steep slopes and in the gorges fringing the Coastal Plateau, beneath the scarp of which the Ecca-Beaufort boundary runs.

In the valley of the Umgazi the top of the Ecca beds reaches the foot of Mlengana Hill, a remarkable cylinder of *dolerite*—an outlier of the sheet fringing the plateau—which rises from a razor-backed ridge of shales, along the flank of which the main road to Libode is cut.

The scenery in this neighbourhood and in the irregular valley of the Umzimvubu is magnificent, the depth of the forest-clad gorges being sometimes no less than 1,500 feet. The conspicuous hills, Mabululu, Amajoli (2,591 feet), etc., grouped together on the watershed between these two rivers are due to outliers of the Beaufort beds of the Plateau supported by a thick sheet of dolerite.

No recognisable fossils were obtained from the shales but they are frequently crowded with smooth fucoid-like impressions similar in nature to those which characterize these beds in the northern Karroo.

## The Beaufort Series.

These beds occupy the whole of the Coastal Plateau, but are also brought down along the Ngqeleni coast by the monoclinal fold as already stated (Fig. 1 and Map).

The average dip of the rocks over this wide area is about 2°, and on account of this low inclination and the existence of numerous dolerite sheets and dykes the disturbing effect of which cannot accurately be gauged, it is impossible to obtain an exact estimate of the thickness of the series over the plateau. Along the belt of flexure, on the other hand, there are several points where a more reliable estimate can be made on account of the much higher and more regular dip of the strata and the total thickness of this series allowing for dolerite sheets intruded parallel to the bedding planes

lies between 8,000 and 8,500 feet.
exceeds the general estimate given for
Beaufort series in the Karroo, but it
the thickness has been considerably
last-named region.

In the Karroo the Beaufort beds
into three groups—an Upper, a Mic
characterised by a different suite of r
Stormberg region it is possible upoi
separate the Uppermost from the M
Burghersdorp beds having been given
the other two divisions can be di
mapping of the Midlands remains to

In the Transkei the Burghersdorp b
occupy the ground at the base of the
separation of this group from the pres
beds has been effected without diffi
sub-divide the remainder of the series
of the lithological uniformity of the
is believed, by reason of the lack of
softer strata. It appears from the de
and Professor Schwarz that their I
respond to the Burghersdorp beds, b
the south does not fit exactly with t
the first-mentioned name has not
connection.

The Kentani beds are probably t
portion of the Middle and Lower Beau

*The Lower and Middle B*

Sandstones, medium to fine in grai
colour, predominate, but as usually se
the rocks have outcrops typically
They are invariably felspathic, in som
as for example on a spur of the plat
Nomadolo towards Wilo. A sandston
the base of the series at the Zibun
composes to bright red and orange-colc
a soil of considerable brilliancy.

Some of the sandstones are very
possess a fine vertical jointing, so t
sections along the deep river gorges the
for sheets of columnar dolerite.

---

[1] Annual Report of the Geological Comr

Mottled sandstones are not at all common. They appear for instance at the Ngqeleni beacon and on the Umtata Commonage, where the material has been extensively used for building purposes. Purple and lilac-coloured sandstones only make their appearance toward the upper limit of this formation.

The softer beds are seldom true shales, more commonly they are blue, green and grey sandy rocks fine-grained in texture and crumbling under the action of the weather to form yellow or drab sandy clays. Much of this material is hard but thinly bedded, and can be called "flagstone." Red and purple shales and mudstones are only rarely seen, except along one very marked horizon which can be followed from the Umtata River at Mandloveni Trading Station up the western side of the Cumgce Valley past Buntingville Mission. It was hoped to employ this horizon in sub-dividing the series, but towards Libode there is a great development of dolerite. and along the Tsitsa River this zone was not detected.

Along the coast, however, what appears to be the same belt of red rocks can be followed for a few miles at Hluleka (Map 2). The zone is about 700 feet in thickness and shows blue, grey and bright red shales, the latter in beds of from five to six feet in thickness alternating with flaggy strata and thin sandstones.

At Hluleka Trading Station (now closed) reptilian remains were obtained from sandstones immediately below the red shale group, and these appear to be Dicynodont in type. The bones did not occur together but were embedded separately in the sandstone along nearly the same horizon for a distance of over a hundred yards.

Bones were observed elsewhere along the coast usually embedded in calcareous sandstone or in calcareous nodules; none were obtained inland. Indeed the fine sea-washed surfaces of rock on the Pondoland coast forms the only satisfactory hunting ground of the fossil collector; inland no remains were obtained except fragments.

Along the beach, as one gradually crosses the strike of the beds, all dipping seawards, the nature of the strata can be excellently seen, and the predominating arenaceous character of the deposits is realised for the first time, and their lithologically uniform nature now becomes apparent. One sees the false bedding in the sandstones, the frequent occurrence of calcareous nodules and concretions in them, and the rarity of soft dark shales which can profitably be searched for plant remains.

The block of farms at Umtata stret strata which has been relegated to the and which is characterised by the abse shales and by the presence of dark gr flagstones accompanied by hard sand instance along the gorge of the Umtata miles. This zone stretches north-eas spicuous for instance along the Tsitsa R hood of the celebrated falls of that name.

Some thick sandstones in this belt g ment running northwards from Elutub rather uncommon feature in an area solely by dolerite ridges. On this sa forms a centre from which a number radiate, there stands the beacon Ese highest point on the Coastal Plateau wh from the edge of the Inland Plateau is

*The Upper Beaufort or Burgh*

A short distance to the west of Umt bands make their appearance, and aft mudstones and sandstones become very the softer strata are exposed.

The boundary of the Burghersdorp manner runs northwards from Centul Ncise, crosses the Umtata River, runs r of the Nqadu Hill past Esdwadweni a the road bridge on the Tsitsa River.

The area lying to the west of this li the tract occupied by these beds furthe Qumbu and Mount Frere, and the des given in last year's Report will apply he

Fine sections of the red and purple in many localities, more especially wh have cut enormous ramifying trenches excavating huge channels in the soft, A striking example of one of these tr development close to the Lower Myol far from Baziya. A characteristic fe overlying the purple beds is a peculia tint. Some of the mudstones are vi a deep purple-black, weathering to bro

In the mudstones there are frequ concretions, pale greenish or pink in tint The sandstones are yellow, medium-gr

Continuous sections are afforded by the cuttings on the road leading from Sundwana in Elliot past Qutubeni to Engcobo. Other localities are Tabase Nek, Mhlahlani School, Jenca, Esinxaku, Culunca, Gqungqa, etc.

The thickness of this sub-division as measured to the west of Umtata does not exceed 3,000 feet probably ; further north, however, in Mount Frere its value appears to be less. On the sea-coast just south of the Umgazana River beds belonging to this horizon are brought down by folding (Map 2.). The softer red beds are seldom seen and the formation is certainly more arenaceous than inland. The rocks are mostly massive, yellow to grey hard felspathic sandstones in thick beds, giving rise to a rugged coast-line showing magnificent precipices rising vertically 350 feet at Brazen Head and culminating in Ndluzula Hill adjoining, 800 feet in height. This was certainly the grandest piece of coast-line examined.

## The Molteno Beds.

These beds described in the Reports for 1909 and 1910 maintain their lithological character and give rise to the same type of country in the area in question.

The finger-like spurs, bordered by cliffs composed of the pebbly Indwe sandstone are finely developed around the headwaters of the Umtata and Inxu Rivers, the streams taking their rise in narrow deep kloofs usually clothed with forest and with slopes strewn with blocks broken off from the precipices which wall them in. Here and there branch streams, taking their rise on the plateau, tumble over waterfalls into the gorges below. East of Mount Grant (5,255 feet) one finds the Qelana and Qoqora Rivers with the beacon Matiwana (5,625 feet) overlooking the basin of the Mhlahlani. This ridge forms a barrier stretching out north-westwards towards Tsolo, and is commonly known as the Matiwana Range. At its termination there are outlying peaks, namely, Jenca Hill, the conical hill Bele (4,854 feet) and the smaller but more conspicuous Lutshinsho Hill, capped with dolerite and jutting above the forest.

On its inland side the Matiwana is broken into long nearly-flat-topped spurs, separated by the valleys of the Qakela, Umga and Qaqala Rivers. The same type of scenery is continued in the high ground between the Inxu and the Tsitsa Rivers, with Qalbomvu (4,804 feet) as the culminating point, while an outlier builds the regular cone known as Tsolo Peak, close to Inxu Trading Station.

At a point just above its junction with the Inxu the Tsitsa River issues from a narrow "poort," beyond which the valley

is found to open out into a broad flat-bottomed tract, known as the Tsitsa Basin hemmed in on all sides by ridges and precipices mostly fringed by the Indwe sandstone. Outliers of Molteno sandstones cap the hills known as Sampompolo' Ndhlovu or Dwabe Peak (4,988 feet) and Ntaba Sigogo across the Tsitsa in the Qumbu Division.

A similar but much smaller basin is found to the west of Engcobo on the Xalanga boundary holding the Umtinthloni Forest.

An interesting feature is the large number of boulders of Indwe sandstone strewing the floors of the valleys and clearly derived from the cliffs, which are now some distance away. This is perhaps best seen at Jenca Trading Station where the main road passes across an area spread with rounded, subrounded or angular masses of pebbly sandstone in some cases exceeding a yard in length, while the nearest cliffs of this rock are sometimes fully two miles distant.

The interest attaching to the Molteno beds in the area under consideration is the occurrence of coal in two localities. The first of these is at Zadungeni, on the main route from Elliot to Engcobo, a brief reference to the occurrence having been made in the Annual Report for 1903 (p. 179). The seam has been opened up in a wooded gorge two miles west of Zadungeni Trading Station, and the coal is hauled up from the adit to the top of the plateau by means of a wire-ropeway. The section of the seam varies slightly from point to point, especially in regard to the uppermost coal, thin shaly partings making their appearance or vanishing, while the sandstone roof also undulates somewhat.

The section is as follows :—

| | |
|---|---|
| Solid sandstone roof. | |
| *Coal* (with two thin partings) .. .. .. | 9 to 11 inches |
| Grey-brown mudstone (variable) .. .. | 2 ,, |
| *Coal* .. .. .. .. .. .. .. .. .. .. | 9 ,, |
| Hard mudstone .. .. .. .. .. .. | 13 ,, |
| *Coal* .. .. .. .. .. .. .. .. .. .. | 10 ,, |
| Black fissile carbonaceous shale .. .. | 6 ,, |
| Hard mudstone .. .. .. .. .. .. | 18 ,, |
| Very impure coal .. .. .. .. .. .. | 7 ,, |
| Mudstones and sandstones, etc. | |

Altogether there are from 28 to 30 inches of coal in a seam of nearly four feet. The material is semi-anthracitic, as is shown by the following analysis made by Mr. J. G. Rose, F.C.S., in the Analytical Laboratory, Cape Town, in 1904 :—

| | | |
|---|---|---|
| Moisture .. .. .. .. .. .. .. .. .. .. .. .. | 1·01 | per cent. |
| Ash .. .. .. .. .. .. .. .. .. .. .. .. .. .. .. .. | 20·01 | ,, |
| Volatile matter .. .. .. .. .. .. .. .. .. .. | 10·99 | ,, |
| Fixed carbon .. .. .. .. .. .. .. .. .. .. .. | 67·14 | ,, |
| Sulphur.. .. .. .. .. .. .. .. .. .. .. .. .. .. | ·76 | ,, |

This is almost identical with the analysis of the Cala coal in the Report for 1903 (p. 178), a fact which is not surprising perhaps seeing that both coals belong to the same geological horizon, namely, to the Indwe seam.

The available area of coal seems satisfactory, but there are several narrow, vertical dolerite dykes cutting through the field very close to the workings; these should be avoided as far as possible in mining operations.

The second locality is at the Intwyenka Trading Station, on the main route between Maclear and Tsolo, the coal being exposed both in the roadway at the head of the cutting and at the head of a stream a couple of hundred yards to the north of the store itself. There are two thin seams, both of them being exposed along the road, but only one, the upper probably, in the second locality; the drive, unfortunately, has collapsed so that a section cannot now be measured. There does not appear to be more than 15 inches of coal in the top seam, though there may be other layers deeper down. The coal is like the Gubenxa seam with which indeed it corresponds lying as it does above the Indwe sandstone.

About two miles due east of the store the plateau is constricted to an extremely narrow neck to give rise to a wide irregular expansion beyond. At a few points on the approaches to this causeway black shales have been washed out of the soil evidently from the extension of this coal seam. The area around Intwyenka being fairly free from dolerite intrusions, certainly deserves further prospecting.

The Molteno beds are brought down on the sea-coast by folding and occupy an area about a mile and a quarter in length and much less in width, tapering away at the headland on the south bank at the mouth of the Umgazana River (Map 2). These beds follow conformably the Beaufort sandstones and are dipping at angles of from 20° to 30° towards the north-east; the strata are traversed by a number of dolerite sheets and dykes. The coarse-grained porous "glittering" sandstones, crowded with small pebbles of white and smoky grey quartz and rich in fragments of felspar, are identical in every way with the pebbly sandstones of the Molteno beds although the nearest outcrops of that formation are no less than 50 miles distant, near Tsolo. The other

sandstones are greyish in colour, finer grained and felspathic; no shales were observed and, unfortunately, no plant remains were obtained to confirm the conclusions arrived at. Fully 1,500 feet of Molteno beds are represented here, the succession being terminated by the Cretaceous conglomerates of the headland.

## THE UMGAZANA (CRETACEOUS) BEDS.

These rocks, mostly conglomerates, compose the little rounded hill commanding the entrance to the Umgazana River (Map 2), and are well exposed over a platform cut a little above tide-mark. Altogether the area covered by these rocks is not more than 300 yards across, and though the thickness of strata exposed cannot exceed 300 feet, yet considerable interest attaches to the occurrence which recalls in its habit and lithological characters the Embotyi beds[1] which were recorded by Messrs. Rogers and Schwarz from the coast 30 miles to the north-east of this point.

On the river side the junction of the conglomerate with the Molteno sandstones is not actually exposed, but the boundary can be located to within a very short distance. The base can be followed diagonally up the western slope of the scrub-clad hill and obliquely down the seaward face, where there is a small cliff showing soft yellow-weathering (Molteno) sandstone dipping at 25° and giving rise to a small cave, while above this the conglomerate is seen with a slightly lesser inclination.

On the beach the sandstone is found to have a rather uneven surface, and where it projects into the conglomerate the dip of the latter is at such a point greater.

The conglomerate is an intensely tough grey-green or green-black rock crammed with pebbles and boulders principally of dolerite—the greenish colour is due to the large quantity of dolerite débris in it. There are also boulders of Karroo sandstone and shale, and lydianite and quartzite from the action of dolerite upon the last-named, while interesting accessories are lumps of amygdaloidal basalt and agates of various kinds. The larger inclusions are rough or only slightly worn; the smaller are rounded and often finely polished. The bulk vary from a few inches to a foot in diameter, but the size ranges up to eight feet, and one block of Molteno sandstone was discovered 12 feet in length. It is noteworthy that these large inclusions do not appear at the very base of the formation. There are layers of coarser and finer grained

---

[1] Ann. Rep. Geol. Com. for 1901, p. 44.

conglomerate alternating with green grits through which lie scattered pebbles, and with green-grey sandstones and even dark flaggy beds devoid of pebbles. The highest rocks seen were still conglomerates, and the whole succession is dipping at an average angle of 20° in an east-north-easterly direction, *i.e.*, at an inclination a little lower than that of the underlying Molteno beds and with a strike a little different. In a few places there are slight east-west displacements of the beds but otherwise the conglomerates are unaltered and the pebbles uncrushed.

In some sandy layers carbonised wood was present, also a fragment of a fern frond having a close resemblance to *Cladophlebis*, while in the upper portion of the conglomerate a few lamellibranch fossils were discovered, but the shells being formed of crystalline calcite were impossible to extract. A fortunate discovery was a tiny pocket or lenticle of hard limestone crowded with marine fossils in the midst of coarse conglomerate, and this yielded among other forms a portion of a *Baculites* thus determining the age of the beds as Cretaceous. Mr. H. Woods, of the Sedgwick Museum, Cambridge, has kindly examined the material and has provisionally identified the following forms :—

*Baculites capensis ?*
*Pseudomelania Sutherlandi.*
*Natica.*
*Trigonia Shepstonei ?*
*Arca* (*Barbatia ?*)
*Pecten.*
*Panopea.*
*Corbula.*
*Thetironia* [=*Thetis*].

He adds ' The fauna resembles that of [the Umzamba beds of] Pondoland and is probably of the same age [Senonian]. It should be noted, however, that hitherto *Thetironia* (syn. *Thetis*) does not seem to have been recorded in beds later than the Cenomanian. But I see no reason why it should not have survived longer in some regions."

The Umgazana beds are practically identical in character with those at the Embotyi River mouth, and like them show that the Karroo beds and dolerites were exposed along a shore line in cretaceous times. The fact that the former rest upon Molteno beds and contain agates and pebbles of amygdaloidal basalt comparable with the volcanic rocks of the Drakensbergen indicates that the Stormberg beds, including the volcanic zone, formed portion of the cretaceous coast line or built higher ground not far inland. The tilting of the

conglomerates proves also that the flexuring and faulting which affected the Pondoland coast took place during or after cretaceous times, a view which is in harmony with the evidence that has been obtained in Natal.

### The Dolerite Intrusions.

While narrow vertical dykes are confined to the west of a line drawn from Buntingville Mission to Shawbury, dolerite in the form of sheets is ubiquitous.

In the tilted coastal region the successive sheets produce narrow outcrops parallel to the strike of the beds which they invade and partake in any irregularity in direction of the latter (Map 2).

One of the lowest and certainly the most important of these sheets comes into prominence along the banks of the Umtakatyi River expanding at Ntabancuka Trading Station and forming a ridge on which stands the beacon Pelapela (987 feet). After crossing the Mvilo River it builds the hill Kunkulu (1,378 feet) and produces a block of rugged country to the east of that eminence, conspicuous from afar being a dome-shaped mass known as Mpotshotsho Hill.

This sheet is dipping seawards but along the axis of the monoclinal fold flat-lying outliers of dolerite are found close to Xambuza Trading Station and on the Tengu and Bomveni Hills.

The sheet is found a little further inland, having a low north-westerly dip, agreeing with that of the strata into which it has been injected.

The sheet runs up the gorge of the Umtata River as far as the odd bend known as Mpindweni, where it disappears below higher beds and gives rise to a waterfall. Cropping out below the cliffs on either side it rises gradually to produce the tree-clad plateau at Nomadolo (2,135 feet) with its forested escarpment overlooking the Coastal Belt. The sheet strikes northwards crossing the Umdumbi River where it determines a picturesque waterfall. Here it splits into two sheets, the lower extending the plateau to Qokama (2,164 feet) and being about 300 feet in thickness. At the Trading Station of that name an unfailing spring issues from the dolerite at a point near the very summit of the flat-topped ridge.

The sheet is cut through by the Ngqeleni and Umtakatyi Rivers, giving gorges with almost vertical sides formed of bare nearly unjointed rock ; on the edge of one of these fine cliffs there stands the Trading Station of Noxova. Close to Old

Bunting the intrusion must be over 500 feet thick and at one point two and a half miles south-south-west of the store the igneous rock has weathered out into huge isolated boulders projecting far above the surface or resting upon the soil. Patches of hardened sandstones and shales adhere to the upper surface of the sheet thus producing the flat-topped ridges surrounding the head of the Mvilo River.

Beyond Old Bunting the sheet has a rapid westerly dip and passing Qiti Trading Station drops into the valley of the Umgazi, where that river has cut a precipitously sided loop into it, and running diagonally up the side of the next ridge culminates in fine precipices known as the Macibi at the foot of which there stretches a large area of forest.

The upper portion of this sheet after leaving the Umdumbi River runs up the gorge of the Umtakatyi to a little beyond the drift on the main road between Ngqeleni and Libode and then rises to the summit of the plateau, the upper part of the sheet becoming hereabouts light-coloured and granitic in texture. Thin sections of the rock (830, 2788) show a typical granophyric structure, the quartz and felspar being intergrown to form micropegmatite. The ferromagnesian minerals consist of pale hornblende and some biotite, both altered for the most part to chlorite. Ilmenite is present in large plates together with a little sphene. The sheet covers a considerable area near St. Barnabas' Mission, where it receives an easterly dipping feeder which can be followed northwards until it crosses the Umzimvubu in the big bend at Lukuni. At Mlengana there is some most striking scenery down the winding gorge of the Umgazi River, the most remarkable sight being Mlengana Hill, a cylindrical tower of dolerite with vertical sides perched on a sharp-crested ride of shales. It is an outlier of the sheet which determines the edge of the plateau, an intrusion that can be followed round the edge of the extraordinarily dissected tableland on which the trading stations of Nkanga, Zibungu and Lukuni stand. Along the road-cutting at Mlengana the intrusion is a triple one totalling altogether 1,000 feet. At Nkanga in the valley of the Umzimvubu these sheets unite and split several times, the outcrops of the sheets giving rise to fine cliffs. Particularly must attention be drawn to the precipices 1,500 feet in height just across the river with outlying masses projecting into bends in the stream. Up the Tsitsa River there is a maze of dolerite sheets with inclined feeders here and there; one of these passes through Mtombe and Marubeni, and upon its southerly termination the village of Libode has been built. Another intrusion passes Elutubeni Trading Station and caps the ridge overlooking

the Rainy Mission, while an offshoot striking southwards expands and covers a wide area around Mount Prospect Trading Station, the thickness of the sheet in this neighbourhood being probably not less than 1,200 feet. About three-quarters of a mile to the south-west of the beacon Dimbe on the summit of a hill there are masses of dioritic rock, a more acid phase of the upper part of this intrusion.

The main road between Libode and Umtata runs along the outcrop of this dolerite, which crosses the Corana River, doubles back upon its course and strikes northwards crowning the hill Gongolulu (3,697 feet). Here it becomes insignificant for a short distance, but turning westwards swells out to form the Nqadu ridge (4,280 feet). It then makes a complete semicircle having a diameter of nearly eight miles with the village of Tsolo on the opposite side of the curve. Its habit is that of one of the basin-shaped sheets found elsewhere in the Cape Province, and its outer edge forms a convex escarpment overlooking the valley of the Mjika River and dipping inwards at a low angle below the Tsolo block of farms. It is continued across the Tsitsa River giving rise to complicated outcrops between Culunca and Sulenkama.

A remarkably fine example of a basin-shaped intrusion is drained by the Mhlahlani, a tributary of the Umtata River, which rises on the slopes of the Matiwana Range.

The inner diameter of the ring is four miles, but on its eastern side the outcrop is broad, the dolerite sheet rising to give a conspicuous escarpment on the southern edge of which is situated the beacon Kambe, while at the north denudation has just severed the continuity of the intrusion with the horizontal columnar sheets overlying the Indwe sandstone in the Matiwana Range over 2,000 feet above the grassy floor of the basin. The jointed nature of such dolerite enables the rock to act as a storage reservoir and to feed strong and permanent streams. A case in point is the Nyembesi stream, which, in spite of its tiny catchment area on the dolerite ridge of the Kambe Hill, pours over the edge in considerable volume and is the source of the water-supply of Umtata 14 miles distant.

A westerly dipping sheet determines the ridge between Tabase Nek and Centuli, while one with southerly dip runs parallel to the main road between Umtata and Engcobo, and through a "poort" in it the Bashee River runs. What is possibly its westerly continuation is cut through diagonally by the Xuka River close to All Saints' Mission. The area between Engcobo and the Xalanga boundary is a network of dolerite sheets often several hundred feet in thickness dipping and striking in various directions, uniting, diverging and then reuniting.

Regarding the vertical dolerite dykes there is very little to say. They are most numerous near Engcobo, where their predominant strike is north-north-west; a long dyke with this direction passes close by Baziya Trading Station. The rough country extending from the Matiwana to the Tsitsa Basin is seamed with narrow dykes, most of them not more than four or five miles in length and running in all directions.

One such intrusion striking a little to the north of east and passing a short distance to the north of the beacon Qalbomvu near the Intwyenka occupies a line of fault, the strata to the south having been thrown down a distance of fully 150 feet in places. As a rule the displacement caused by a dyke is small.

An east-north-easterly dyke runs from Nqadu past Ncolora Trading Station to the Tsitsa gorge, being worthy of note since narrow vertical dykes are rare in this more easterly portion of the Transkei; as mentioned already such intrusions are practically absent east of the line drawn from Buntingville to Shawbury.

A few notes can be made upon the mode of weathering of the dolerite in certain parts of this area. In some cases the boulders in the ground are not rounded masses exhibiting exfoliation as in the Karroo, but are more or less angular in character with a highly pitted exterior; the rock is fresh up to the very surface as a rule. Round this core there is a shell usually a few inches in thickness—often much more—of extremely decomposed ochreous dolerite—a golden yellow sandy clay, very often with a tinge or a spotting of green or grey; it may grade into pink or red earth. On the surface of these earth-encrusted blocks there may be a skin of hydrated ferric oxide (limonite) from a quarter to half an inch in thickness, sometimes smooth but more usually giving a gently rough or mamillated exterior.

In the course of the decomposition of the shell the iron set free has become concentrated at the exterior, leaving within a soft product probably rich in aluminous compounds.

In certain areas, for example at Nomadolo, bright red soils, almost vermilion-coloured, result from the weathering of dolerite. Such areas are generally largely soil covered; they also not uncommonly exhibit small hollows or depressions in the surface which hold water for a time after the rains.

Petrologically the dolerite is everywhere a coarse rock showing ophitic intergrowth of labradorite felspar with augite accompanied by a small amount of magnetite and ilmenite, while olivine may be present in fair amount.

In certain cases the augite possesses a diallagic habit; lustrous planes are developed in the crystals so that the

rock may show glistening silvery patches from an eighth to a quarter-of-an-inch across. This is best seen where the rock is commencing to weather, and even when the dolerite has decomposed to a yellowish earthy product, the igneous origin of the material can be recognised by these micaceous looking patches resulting from the weathering of the augite.

## The Tilted Coastal Section.

On the lower reaches of the Umgazana River the Ecca shales are found lying quite flat or with a very gentle westerly dip, nowhere exceeding two degrees (Fig. 1 and Map 2). Between the Umgazana and the Umgazi Rivers a seaward dip first becomes evident at a distance of about three miles from the shore, the inclination increasing until on the coast itself the last exposures possess dips of from 20° to 25° towards the south-east.

Further to the south the Ecca beds are cut out by a fault of considerable magnitude, which strikes due eastwards from near Maqebevu Trading Station, making a slight bend so as to pass just north of the Umgazana store. Beyond this point its course is concealed by the alluvial plain of the river, but it is not unlikely that the fracture passes along the foot of the hills bounding the delta, while it may have determined the coast line beyond the Umgazi mouth, possessing as the latter does a marked east-west trend terminating in precipices several hundreds of feet in height.

While the Ecca shales are lying almost undisturbed on the northern side of the dislocation, the strata on the south are the Beaufort beds dipping eastwards at an average angle of 12°, this value increasing in amount seawards until at the coast the Molteno beds have been brought down with a north-easterly inclination of from 20° or 30°.

South of the fault the Beaufort beds occupy a strip of country extending an average distance of six miles inland from the coast, the strata being bent into a moncline with one limb dipping seawards and with axis directed nearly parallel to the shore, that is to say, north-north-east. (See Fig. 1). The Umgazana Fault appears to have been produced simultaneously with the flexing of the strata, and all its features may be paralleled on a small scale by bending the centre of the edge of a book and producing a tear across the pages. A downward drag at the Umgazana Headland will explain the north-easterly dip of the Molteno beds and the south-easterly inclination of the Ecca shales just across the river mouth.

Seeing that the full thickness of the Beaufort beds, as well as most of that of the Molteno beds, has been brought opposite

the Ecca the maximum throw of the fault cannot be less than 10,000 feet and will be much more if as is most probable, the cretaceous conglomerates owe their position to its effect. It must be noted here that north of the river mouth the place of the cretaceous rocks is taken by horizontally lying consolidated calcareous sands and conglomerates of recent age cropping out along the beach. (See later.)

The direction of throw and strike of the Umgazana fault agree with the dislocation by which the Table Mountain sandstone is brought into contact with the Karroo beds and the Embotyi conglomerates (probably of cretaceous age) to the north of St. John's.[1]

At the mouth of the Sinangwani River there is another line of fault also striking east and west and clearly with downthrow to the south, though the amount cannot be estimated. With this exception the strata are found dipping in an even and regular manner and unaffected by faulting until the neighbourhood of the Lwandili River is reached. The dolerites form sheets from 100 to 300 feet in thickness injected parallel to the bedding planes and making outcrops generally coincident with the strike of the latter.

The shore-line cuts very gradually across the strike so that as one goes southwards lower and lower beds make their appearance in wave-washed sections enabling a close study to be made of these Beaufort beds.

At the Lwandilani River mouth the strike changes very suddenly first to south and then to south-east, so that the coast-line cuts nearly at right angles across the strike of the rocks; in this change of direction the dolerite outcrops also partake. For a distance of about five miles, right down to the mouth of the Umtata River lower and lower beds appear dipping north-eastwards at an average angle of 25° without any sign of the underlying Ecca which one would expect to find appearing south of the Umdumbi River.

The thickness of rocks laid bare in this coastal section is apparently 10,000 feet, which is far in excess of its true value as measured further to the north. Step-faulting is first seen immediately to the north of the Lwandili mouth and becomes of great importance in the section between that river and the Umtata. The discrepancy in the apparent thickness of the beds can thus be largely explained as being due to repeated faulting.

The strata striking south-eastwards are traversed by innumerable parallel faults in the direction of the dip (north-

[1] Ann. Rep. Geol. Com. for 1901, p. 45.

east) and which, therefore, run obliquely across the beach. These faults, almost without exception, have their downthrow on the eastern or seaward side and the outcrop of each bed is shifted by the dislocation in steps backward (*i.e.*, to the south), a distance varying from a few inches up to as much as 50 yards. In most cases the faults are clean cut and sharp and the strata otherwise unaffected, but at several points the strike appreciably alters along the fault line. In other cases the beds, especially sandstone layers, have been cracked and brecciated, and this shattering may occasionally cover a belt of from 20 to 50 yards in width. It is important to note that in three cases at least the dolerite intrusions have been cut off and displaced in the same manner ; hence it is certain that all the faulting took place after the injection of the igneous rock and that the date of the step-faulting was of post-Jurassic age.

Just before reaching the mouth of the Umtata River the strata commence to dip northwards, while across the opposite bank there are magnificent sea cliffs, in which the field-glass shows the strata dipping towards the north-north-west and north-west at a moderate angle.

There is therefore an anticline at the mouth of the Umtata River analogous to a roll in the monoclinal flexure, and this disturbance can be traced in a north-north-easterly direction past the drift on the Umdumbi River to a point on the Umtakatyi a little over a mile above the Trading Station of that name, beyond which the effect of the undulation is lost.

How much further the monocline extends down the Mqanduli coast is not known, but in Kentani, 45 miles to the south-west the Beaufort beds possess very low angles of inclination.

The vexed question as to the origin of the south-eastern coast-line of South Africa, whether it has been determined primarily by folding or whether on the other hand by faulting, can hardly be seriously discussed in view of the small proportion of it yet examined. It is hoped that more evidence will be accumulated in the course of the survey of eastern Pondoland this coming season.

## Recent Depression of the Coast Line.

The coast-line between the Umtata and the Umgazi shows no trace of recent shore deposits that may be construed as a sign of recent elevation except at one spot only.

At this locality—one mile south of the mouth of the Umgazi—there are hard sandstones, often coarse-grained, fairly well but slightly irregularly bedded resting upon Ecca shales and

dolerite. The outcrops attain a height of at least 35 feet above the beach, above which there is found reddish and greyish blown sand which mantles the coastal hills.

About three-quarters of a mile further to the south these same rocks crop out along the beach for about 600 yards, producing a small promontory. They are cut nearly level with low-water mark with a small step or cliff rough and eroded into irregular masses, rising to a height of eight feet above high-water mark. The upper limit is hidden by blown sand containing shells of *Helix*, while further to the south right down to the mouth of the Umgazana there is a white sandy beach separated from the alluvial plain by a chain of low sand-hills partially fixed by vegetation

The beds are hard calcareous grits exhibiting stratification which is either horizontal or with a slight sea-ward dip. In places there are pebbly layers commonly not more than a foot in thickness. The pebbles are very well worn and rounded and consist principally of dolerite, lydianite and Karroo sandstone. The beds contain a good deal of broken shelly material and one prominent layer is crowded with fragments of a rather large *Ostrea*.

It is of some interest to find that these deposits which are similar in character to the recent limestones and consolidated sands characterising the south-western coast of the Cape Province, should occur on the north or upthrow side of the Umgazana fault, but the evidence is of too slender a nature to be regarded as a definite proof of upheaval of the shore.

On the contrary, the physiographical study of the coast obtains everywhere in this section clearly-marked proofs of a recent depression of the continent which is in harmony with the observations that have been made in Natal as well as further to the south-east, outside the Transkei. Each of the rivers shows just before entering the sea a sudden expansion, not only of its channel, but of the valley itself, and curves across an alluvial flat which is only a little above sea-level. The actual mouth is generally narrow, either both sides being formed by low hills or else there is a much wider opening in the coast-line with the river touching one of these ridges while the gap beyond is bridged by white sand forming low dunes; the latter case is the more common.

During the dry winter season the sand may be continuous across the mouth and the water thus dammed back forms a lagoon, the excess filtering slowly through the sand and thus finding its way into the sea. This is only true of the smaller rivers, the larger ones having a sufficient flow to prevent the development of such a barrier.

The mouths of the rivers resemble those characteristic of "drowned valleys," and the main points in which they differ from those of normal streams may be summarised as follows.

Down to within a few miles of the shore the rivers wind from side to side in valleys of variable width though generally flat-bottomed, while at the outside of the numerous bends there are cliffs sometimes several hundred feet in height and within each curve there is usually a flat composed of alluvial soil and occasionally of gravels. These wooded knolls continue right down to the coast and in most cases rise abruptly around the alluvial expansion at the mouth itself. The gradient of the river is generally regular and constant for at least several miles before reaching the sea instead of gradually diminishing in value in a seaward direction. On arriving at a distance of from one to three miles from the coast as a rule the gradient ceases abruptly, and this point of inflection marks the limit of the effect of high tide. From this spot onwards the channel widens rapidly so that the breadth of the stream and that of the lagoon is often out of all proportion to the volume of the stream itself and to the drainage area. This is more marked perhaps in the Lwandilani River than in any of the others. The Mhlonga River has a remarkable crescent-shaped lagoon occupying a basin about a mile across, the drainage escaping through a gap in the hills forming the coast-line.

The Umgazana has a rather large alluvial plain, the length being about three miles while its average breadth is about one mile. The brackish soil being bush covered and the land being subject to flooding in the wet season, no use has been made by the natives of this ground for the purposes of cultivation. In this connection it may be noted that the smaller streams and rivulets within a few miles of the shore contain water which is generally saline and not infrequently undrinkable. The explanation is no doubt that salt spray is carried inland from the beach by the prevailing southerly and south-easterly winds and deposited on the surface of the ground and on the vegetation.

# GEOLOGICAL SURV

OF

# PART OF THE STORMB

BY

ALEX. L. DU TOI

# GEOLOGICAL SURVEY

OF

# PART OF THE STORMBERGEN.

By Alex. L. du Toit.

The area surveyed consists of about 450 square miles of country extending westwards from Dordrecht and northwards to beyond Jamestown, the greater portion of which falls within the Division of Wodehouse, the remaining part belonging mostly to Aliwal North. This work forms the continuation of that done in the Stormbergen in 1904 and was carried out with the object of completing Sheet 26 of the Geological Map of the Cape Province.

The whole of this area was mapped originally by E. J. Dunn[1] in 1876-7 on the scale of about one inch to the mile; the topography shown on his map is far superior to that on the present Divisional Maps. The revision has necessitated only a few alterations in the boundaries of the sub-divisions of the strata building the area, but great changes have been made in the course of mapping the dolerite sheets.

Geologically this area consists of the strata which have obtained their designation from this region, namely, the Stormberg beds, consisting of the Molteno series at the base overlain by the Red beds, Cave sandstone and volcanic rocks as described in the Annual Reports of the Geological Commission for 1902-4 and 1909-10.

It is situated upon the wide shallow syncline of the Karroo, the axis of which runs through Molteno and Barkly East; the Molteno beds crop out therefore to the north and south of the area, while the predominating formation is the Red beds, with occasional outliers of the uppermost horizons.

The whole of this territory exceeds 5,000 feet in altitude, and much of it is more than 6,000 feet above sea-level, while occasional elevations reach or closely approach 7,000 feet, such as Toren Berg and Telemachus Kop; the block of high ground known as the Stormbergen, overlooking the valley of

[1] E. J. Dunn, Report on the Stormberg Coal-Fields, G. 4—'78, Cape Town, 1878.

the Orange River, crowned with the Cave sandstone, constitutes the highest range immediately to the west of the Drakensberg, for it exceeds 7,000 feet in height. The drainage is effected by the Hol Spruit and its tributaries leading north-westwards into the Kraai River, but immediately to the west of this area the rainfall is conducted north-westwards into the Orange River, so this block of country lies almost on the watershed between the Hol and the Stormberg Spruits. To the south the ground terminates in an escarpment overlooking the Sterkstroom—Indwe Railway.

Although this tract is very diversified, yet any part of it can be reached without difficulty. Speaking generally, the hills are more or less tabular blocks of higher ground with steep sides and commonly with flat tops between which the roads are carried with easy gradients.

In some places the valleys are rather narrow, as for instance along the Hol Spruit between Alleman's Poort and Oorlog's Poort, but even here the valley, along which an important highway runs, is flat-bottomed and at several points in its course the stream expands to produce a vley, as for example that on Pronk's Kraal, which is a mile in length and half that in breadth.

Frequently there are open stretches of country from which rise outlying masses of Red beds capped by Cave sandstone, or which are traversed by long rugged chains of hills produced by the steeply dipping sheets of dolerite recalling the scenery of the Karroo proper. Such topography is characteristic of the south-western corner of the area in question.

Conspicuous are Pronk's Berg and the great tabular mass close to Jamestown, which extends southwards from Telemachus Kop to Spitz Kop.

The ground, fed by late summer rains, supports a growth of long grass, but a most interesting feature is the commencement of the Karroo region with its typical flora on the western face of the Stormbergen. Here the Karroo bushes are found westwards from Patriots Klip, the transition from the one type of veld to the other being remarkably well defined.

## The Molteno Beds.

The pebbly grits and sandstones and grey and blue mudstones of this sub-division of the Stormberg series appear in three localities only, namely, at and to the west of Dordrecht, on Mooi Hoek south of Jamestown, and around and to the north of that village.

The beds at Dordrecht were described in the Annual Report for 1904 (p. 82-4), but in the period that has elapsed since then prospecting operations have proved the existence of coals a description of which will be of great interest.

A seam of coal has been opened up by means of adits on the Dordrecht Commonage about a mile to the west of the town, and a little to the left of the road to Jamestown. Boreholes have proved the existence of the same seam round about this spot, but further afield the coal is missing. The area, however, over which the seam exists appeared sufficient to warrant further work and an incline which was put down reached the seam at a vertical depth of 70 feet. The section shows a compound (triple) seam resting upon shales and overlain by 3 feet of black compact rock almost like a fireclay followed by a roof of very massive fine grained grey sandstone. The section of the seam is as follows :—[1]

| | | |
|---|---|---|
| 5. | *Upper Coal* .. .. .. | 8—9 inches. |
| 4. | Hard black shale .. .. | 10 „ |
| 3. | *Middle Coal* .. .. .. | 7—8 „ |
| 2. | Black shales .. .. | 8—15 „ |
| 1. | *Bottom Coal* .. .. .. | 13 „ |
| | Total working seam | 28—30 inches. |

The coal is a bituminous caking variety; it is easily ignited and burns freely in a grate without clinkering.

The following is an analysis made by Mr. G. F. Britten in the Government Analytical Laboratory, Cape Town :—

| | |
|---|---|
| Fixed Carbon (excluding ash) .. | 52·54 % |
| Volatile matter (excluding moisture and sulphur) .. .. .. | 18·23 % |
| Ash .. .. .. .. .. | 27·16 % |
| Sulphur.. .. .. .. .. | 0·66 % |
| Moisture .. .. .. .. | 1·41 % |
| | 100·00 |

Calorific value, 10,700 British thermal units.

As regards its geological position the Dordrecht co[a]
from borehole and other evidence to be close to th[e]
of the Molteno seam, which it resembles to a co[nsiderable]
degree; there are however, other seams at and
Dordrecht (Annual Report for 1904, p. 83), whil[e]
have passed through seams on the farms Jacka[l]
Moordenaar's Hoek a few miles to the west of t[he]

[1] I am indebted to Dr. Rowland, of Dordrecht, for gran[ting]
to visit the workings of the Syndicate and to select sam[ples]

To the north-west of Dordrecht the dip of the strata coupled with the rise of the surface of the country carry the Molteno beds below the red and purple rocks of the higher series, but immediately to the south of Jamestown the former appear again owing in part to a very flat dome-shaped flexure, and the grits and mudstones form an inlier on Mooi Hoek about six miles in length and two in breadth. The area of Molteno beds around Jamestown was described in 1904, and the only point of interest is the opening up of a very impure seam of coal on the high ground on Smiling Vale, close to the base of the Red Beds. Close at hand in the river bed on the next farm, Wit Kop, at a spot a little to the north-east of the homestead there occurs a thin seam of impure coal along with shales crowded with fossil plants, chiefly the remains of *Thinnfeldia*, *Phœnicopsis* and *Baiera*.

## The Red Beds.

This formation has been well described by Dunn for the area in question, the greater part of which it covers. It consists of a series of from 800 to about 1,000 feet of strata in which red and purple shales, mudstones and sandstones play a prominent part with beds of yellow sandstone, which are sometimes conspicuous, sometimes unimportant.

The brilliant colouring of the rocks is destroyed by weathering or in the proximity of igneous intrusions, a feature which is characteristic of these beds elsewhere. Hence, in some places, as for example Oorlog's Poort and Leeuw Fontein, hardly any traces of red colouration are seen, while a little further away the hillsides show outcrops of brilliantly tinted strata.

Magnificent exposures of deep red, maroon and purple beds are to be seen along the high ground extending from Leeuwe Spruit and Winter's Hoek to Swak Fontein and Swem Poort. The marvellous brilliancy of the hillsides, here devoid of soil and fallen material, contrasts strongly with the rampart of yellow-white Cave sandstone forming the crestline of the ridges; the base of the latter is deep red and sharply defined. Excellent sections are seen round the peculiar flat topped elevation called by Dunn "One-stone Hill," with its cap of yellow sandstone giving rise to precipices.

Conspicuous from afar is the peaked hill known as Hangklip, with its pointed crown of sandstone and precipitous face overlooking the Schulp Spruit. The capping owes its preservation to a steeply inclined sheet of rudely columnar dolerite.

Reptilian remains were obtained in a number of localities, being mostly fragments of limbs, bones, or single vertebræ;

an unusually large example of one of th
from sub-division D of the farm Zuurbr
Kop.

Along the main road from Jamestown
south-easterly boundary of the farm R
shaly band yielded a specimen of *Thinn*
is fully 300 feet above the base of the Re
third of the way up in the formation an
of interest as being the first discovery
so high up in the Stormberg series.

### THE CAVE SANDSTONE

Dotted over this country are outliers
and sometimes of the volcanic beds as w
great amount of denudation which has tak
rocks were formed. Most of these outlie
and perched up on the hilltops, but in a fe
at lower levels having been brought down
by disturbances of the strata, while to
Jamestown the sandstone crops out arou
large-tableland overlain by basaltic lavas

The sandstone possesses the same gene
the region to the east, that is to say it is
or pink in colour, very homogeneous and
bedding planes as a rule; its lower and
show marked stratification, while occa
formation is well bedded. It sometimes
as much as 150 feet, for example, on Wo
which is considerably less than in Barkly
in places it is even more attenuated. Th
beacon common to the farms Modder Fo
and Vaalbank the thickness is not more
occasionally in Klip Fontein only 20 feet.

The most interesting feature about th
remarkable way in which it weathers. Th
as Predikant's Kop or Spitz Kop, near J
in point. It is a hill of the "tea-caddy type
body with a rudely cylindrical capping
about a hundred feet in thickness, and it s
from the edge of the escarpment, from
detached by erosion. The contrast betwee
and the brilliant purple-red slopes of the p
is most marked, while from the south-e
there projects at its base a curiously-sha
the whole resembling the figure of a parso
pulpit; hence the origin of the name give

A few miles further to the east and overlooking the farm Uitkyk this sandstone caps a spur which is narrow at the root, but suddenly expands and the serrated character of the surface of the rock gives the summit the appearance of a king's crown.

The most remarkable spot which I have had the good fortune to visit is along the boundary between Lelie Kloof and Klip Fontein, very appropriately named "The Field of Rocks" by Dunn.[1] Here, a low ridge well over a mile in length supports extraordinarily eroded blocks and groups of rocks possessing wonderful outlines. They are sometimes arranged irregularly, but are generally spaced rather evenly to form long avenues of monoliths between which one can walk with ease over smooth grass-covered ground. A few of the larger masses show an undercut base of more laminated sandstone the existence of such a layer being no doubt the determining influence in the development of such marvellous scenery. Towards the north and across a small valley the sandstone surface is broken up in the same manner and this is also the case for a short distance to the east, but to the south the formation passes beneath tough doleritic lavas and the outcrops of the sandstone are surfaces which are smooth, in contrast to those which have just been described. The plateau, of which this is a part, is dissected by shallow kloofs fringed by cliffs of Cave sandstone and possessing grassy or swampy bottoms.

## THE VOLCANIC BEDS.

The lavas of the Stormberg series, overlying as they do the Cave sandstone, naturally occupy very limited tracts in the area under consideration, and the outliers of these volcanic beds are, therefore, few in number and small in size. By far the most interesting of these is found on Pronk's Berg with its flat summit, the cake of lavas being rudely T-shaped in plan, the portion corresponding to the horizontal stroke of the T being a little over two miles in length (arranged east and west) with a breadth of under half a mile as a rule.

The capping consists of from 100 to 200 feet of very compact vitreous enstatite-andesites, rudely jointed and generally breaking with conchoidal fracture. In some varieties there is a marked banding with low angles of dip, obviously fluxion-structure. The rocks at the eastern end of the "table" are devoid of vesicles as a rule, but the very highest lava flow contains occasional oval flattened vesicles, while small agates are abundant, both here and strewing the slopes of the mountainl having been set free from the igneous rock by the process

[1] Dunn, *l.c.*, p. 8.

of weathering. One variety of rock w
pumiceous lava.

These volcanic rocks have a great
specimen to the enstatite-andesites f
in Barkly East, and an examination
under the microscope shows that the
petrologically with some of the lat

Slide 2756 is taken from a black
specific gravity 2·504 and shows
labradorite felspar, mostly small,
and there with the enstatite to produ
glomero-porphyritic, in which case
upon the felspar; the enstatite is
glassy groundmass is abundant, b
grey colour, which is due to vast nu
granules of iron ore and tiny needl
a few small vesicles filled with aga
from a similar rock, not quite so fine
of 2·53. The groundmass is clearer
colourless glass containing granules
and microlites of augite.

A third slice (2758) shows a be
glassy base, in which are set phenoc
and faintly yellowish enstatite, t
frequently clustered together. T
numerous microlites and small pri
augite, within and along the side
ores occur abundantly. There is a
of quartz, but this may represent
by the lava. The specific gravity

An outlier of these andesites less
is found six miles towards the nort
and supported by a pedestal of Red
beacon of Leeuw Spruit is situate
which rises some 700 feet above the

The thin section (2761) is very si
the fresh enstatite and felspar bein
colourless glass. The density of t

On the high ground to the west
all basaltic in composition, var
doleritic types to highly vesicular
considerable development of volc
intercalations of sandstone.

A fine section is found at the l
with Vaalbank, where the Cave san
300 feet of volcanic ash followed by

of lavas (Map) with rudely columnar structure. The ash is greenish in colour with red and purple mottling due to the abundance of inclusions of shales derived from the Red beds; it shows distinct stratification and near its summit includes a few thin layers of basalt, while its colour becomes noticeably redder. At this same point there is a remarkable dyke of green tuff about 100 feet wide that cuts the Red beds and Cave sandstone and merges in the sheet of stratified ash which overlies the latter. It strikes in a direction a little to the south of east towards the basalt escarpment but does not cut the lavas. The dyke represents a volcanic fissure from which material was ejected which went to form the ash-bed or else it must have been a crack or fracture in the earth's crust which became filled with fragmental material ejected by the great volcanic pipe near at hand.

Less than a mile to the north, just inside Modder Fontein, what is almost the same thing is repeated, the strata being cut by a vertical dyke of tuff striking east and west. This locality is just on the border of an area of fracture and subsidence, and it is therefore not surprising to find that a patch of Cave sandstone, volcanic ash and lavas has slipped downwards on the north side of the dyke and towards which the sunken mass is now dipping at an angle of about 20°. By tracing in the field the intercalations of ash and sandstone it is at once seen that we have here one of those interesting cases of the overlapping of distinct lava flows poured out probably from several centres, a feature which elsewhere in this part of the Province has been found to be characteristic of a region of local subsidence caused doubtless by the abstraction from below the surface of molten matter which was ejected from volcanic pipes and fissures close at hand.

Thus along the western boundary of Dank Fontein the Cave sandstone is followed directly by the thick ash-bed which from its softer nature is found along the flanks of the hills or on the lower ground. Traced eastwards this ash-bed becomes split up by a basalt flow, and each of the two layers of ash becomes thinner and at the same time more sandy at its upper limit so that over the south-eastern part of Dank Fontein the thick ash bed is represented by two thin yellow sandstones ashy in places. In the meantime lavas have made their appearance between the ash and the Cave sandstone, thickening to 100 or 150 feet in an easterly direction and being themselves split up by thin sandstone seams well exposed in the south-eastern corner of the farm. Close by the homestead these lower flows are accompanied by brecciated lavas and a small amount of tuff, while the rocks appear somewhat disturbed;

to the south-east again dips of from 5°
these features point to collapse of the
tract of lavas; but the hollow thus proc
partially levelled up by the igneous an
poured forth, for the basalts succeeding t
regular and very gentle dips.

This same overlapping of the vario
clearly traceable to the south on Wo
volcanics here rest directly upon the Cav
been preserved through the fact that th
syncline traversing the farm Klip Font
westerly direction. Two thin bands o
intervals be traced between the volcani
thin have suffered somewhat from bak
heat of the lavas which were poured
section (2770) of one of these hard ro
tiny fragments of basalt of various type
altered, set in a groundmass of small an
and volcanic dust.

A similar rock was obtained from
volcanic plateau on the farm Spitz
extending over Lelie Kloof and into K
preservation to the exceptionally tough
stratum of basalt overlying the Cave san
a coarse nearly holocrystalline lava almo

FISSURES OF ERUPT

The intimate relationship between s
dolerite sheets and the effusive basalt flo
was drawn in the Report upon Maclear,[1]
from a study of the region around Jame

Generally speaking the large sheets o
holocrystalline ophitic structure are no
Cave sandstone or higher beds, the in
being usually narrow dykes possessing a
and by the frequent presence of a small
approaching very closely in petrological
of lava flow.

An excellent example of an intrusion
been a feeder from which some of the ba
remarkable dolerite sheet, ring-shaped
encloses the great volcano on Modder
crops out at the edge of the area of
nearly complete circle four miles in di
directed inwards towards the enclosed v

[1] Ann. Rept. Geol. Commn. for 19

On the south-west the intrusion dies out in the Red beds, and it is noticeable that the latter is followed by the Cave sandstone and volcanics in the normal manner. On the south-east, however, the dolerite sheet strikes southwards through Dank Fontein with a westerly dip and merges with the lavas.

At the conical hill called Telemachus Kop the sheet is a coarse-grained dolerite of specific gravity 2·924, which in thin section (2762) under the microscope shows ophitic intergrowth of plagioclase felspar and augite, small altered olivines, and between these constituents little brownish patches which probably represent altered glass.

Along the boundary of the Modder Fontein volcano, just within the farm Dank Fontein, this intrusion has acquired a totally different facies. The thin section (2769) shows phenocrysts of felspar and serpentinized olivines set in an abundant grey groundmass; the latter is found under a higher power to be composed of minute granules of augite crowded so closely that the nature of the base cannot be determined. There are also small fragments of pre-existing basalt which the intrusion had picked up in its course. The specific gravity is only 2·874.

Traced further southwards the area of igneous rock widens and includes some long streaks of sandstone which appear from the way in which their outcrops pinch out rapidly at the ends to be strips of the Cave sandstone surrounded by the molten material as it poured forth at the surface. On the western side of the volcanic area the same feature is repeated and on the Remainder of Limoen Kraal a sheet of dolerite, here dipping south-eastwards however, cuts diagonally through the Cave sandstone and ash-bed to merge with the overlying basalts. It may indeed be regarded as the extension of the feeder on Dank Fontein.

Another, and perhaps even more striking example, is furnished by the dolerite sill which forms the conspicuous ridge known as the Toren Berg—or locally as the Stormberg—twelve miles to the west of Dordrecht.

This sill is a portion of the network of Karroo dolerites which characterises this area and runs from Oorlog's Poort to Vogel Vley with a general south-south-westerly trend and with a dip of from 20° to 30° to the east-south-east. The ridge is composed of Red beds with a capping of horizontal Cave sandstone through which the sill cuts, the igneous rock forming the summit of the chain and attaining an altitude of fully 6,600 feet above sea-level.

The dolerite elsewhere along this int
seen in an inlier of the sheet in a kloof lea
is the normal coarse-grained ophitic var
traced upwards through the Red beds i
finer grained selvage but retains its n
small though variable distance from the
the level of the base of the sandstone the
to show small vesicles and begins to lo
higher up the rock acquires a typical
being fine textured, sometimes compact,
vesicular. It is important to note that
of the rising intrusion and that the rock cu
enveloping large portions and rendering
the contacts. The summit of the ridge is
weathering and very hard fine-grained li
in some places it is highly vesicular, in oth
recalling the coarse dolerite.

There are no tuffs or breccias here and n
lavas occur resting upon the Cave san
tuff necks occur nearly a mile away along
the contact of the sandstone with this int
development of vesicular structure in the
500 feet indicates that the amygdales ha
the relief of pressure which resulted a
approached the surface, and it therefor
that the basalt was poured out sub-aeria
type of vulcanicity known as a "fissur
section (2755) taken from a specimen
Toren Berg shows the following features
Plagioclase felspar is abundant in the for
crystals or crystal aggregates the min
altered. Augite occurs in granules and
these the felspar may be moulded, bu
minerals are merely in contact. Round
augite, a ring of dusty matter is comm
is yellowish-brown and is no longer gla
substance, dusty, with granules and s
iron ores, needles of felspar, etc. Ar
there is usually a somewhat irregular
dark base penetrated by felspar micro
the vesicle is filled with some zeolite,
chalcedony.

In corroboration of this hypothesis an
cited, this time from a volcanic pipe s
eastern end of Oorlog's Poort almost u
Pronk's Berg.

Along the ridge of Red beds there runs a sill of dolerite about eight feet in thickness, a moderately coarse-grained rock traversed by vertical jointing causing it to break up into blade-like fragments. At about 100 yards distance from the edge of the pipe the dolerite begins to develop amygdales and these increase in number and size as the vent is approached, until, as it cuts through the tuff filling the pipe, it has become a thoroughly vesicular rock with zeolite-filled amygdales arranged in bands running parallel to the dip, which is here at an angle of 10° inwards. The sill can be followed aross the pipe until it thins out in the extremely hard tuff and where last seen it is only a couple of feet in thickness and dipping inwards at a high angle. At both upper and lower contacts the rock is finer grained and more compact than in the centre, while the fragmental material on either side has been baked by it. Obviously when the sill cut through the material in the volcanic neck the local relief of pressure enabled some of the water-vapour occluded by the molten rock to free itself and thus permit the development of vesicles.

Nearly four miles to the north-north-west of this point there is another example of amygdaloidal structure in a dyke and this case presents interesting features since the intrusion is an enstatite-andesite and the dyke is probably the source from which the enstatite-andesites issued capping Pronk's Berg a couple of miles to the south.

This dyke is found cutting through a prominent dome-shaped hill overlooking the steep descent on the road to Mooi Hoek and striking in a north-westerly direction while it dips steeply to the north-east. The central and basal parts of the dyke consist of a light grey markedly amygdaloidal rock decomposed in parts, and the vesicles are often elongated in a direction corresponding to the dip of the intrusion and presumably to the source of the magma.

A thin section (2773) shows both stumpy and narrow prisms of a plagioclase felspar, probably an acid variety, the larger individuals exhibiting zoning. Enstatite is represented by pseudomorphs in bastite and serpentine. The groundmass consists of dusty felspars possibly orthoclase and a lesser amount of quartz in interlocking areas ; it can be termed microfelsitic. In the vesicular portion of the dyke there are often druses over a foot across lined with chalcedony and containing crystals of quartz.

The upper edge of the dyke is dark in colour and vitreous in character ; the thin section (2774) shows crystals of clear labradorite felspar and enstatite, often aggregated, set in a

slightly brownish but clear glass contai microlites of felspar and enstatite to whi are frequently attached; round the crystal aggregates the glass is browner tl

The rock is a typical glassy enstatite-a the lavas of Pronk's Berg to a high gravity is 2·49.

An intrusion with somewhat similar l character cuts the Red beds on the adjoir running in a westerly direction along ground. At the western boundary of t main road from Jamestown to Moltei a fine-grained upper surface overlain b which have been baked into quartzit sheet becomes very vesicular, the cavities in a horizontal plane. They vary in siz one to eight inches in length, but occasi value, the bigger vesicles possessing ve These druses are very abundant, being s to a foot apart often; they are lined white and opaque, but now and then tra part of the sheet is nearly compact, but th with small vesicles; the hard sandsto peculiar radiating wavy ridges and cro forming this intrusion, which probably d in thickness, is light grey in colour, rather to give a smooth bare surface so that r found resting upon it. The thin sectior with characters resembling those of 277 also a good deal of calcite.

This sheet is probably older than th which pass a little to the east of this po

## THE VOLCANIC NECI

In spite of the small size of the are there are quite a large number of volc majority of which are small in diamete light yellow sandy tuff characteristic of t of volcano. The great volcanic neck however, eclipses in size all others tha discovered in this portion of the Cape P addition, a number of uncommon featur

Commencing in the south and south-v of small pipes situated along the conspi of Red beds with an outlier of Cave sanc easternmost beacon of Drooge Fontei

prominent of these necks is formed of yellow sandy tuff, which, though very similar in texture to the adjoining sandstone, yet weathers in an entirely different manner possessing rugged surfaces of pitted and cavernous rock in marked contrast to the smooth outlines of the stratified sandstone from which it rises like a monument. It must have a length of 100 yards at least, but the boundaries are not well defined. Most of the material is like yellow sandstone, but a lot has a peculiar mottled appearance and contains small fragments of sandstone scattered through it. On the eastern side a typical tuff is exposed in a small cave and tuff-like varieties appear elsewhere, but are not abundant.

A second small pipe is found adjoining the first, the tuff breaking the continuity of the sandstone along the slopes of the hill. A third neck is situated at a little distance away on the spur of the ridge, and the contacts with the sandstone are clear. The tuff is crammed with fragments of sandstone and shale, sometimes well rounded and like marbles in size and appearance, giving a rock of very uniform texture, sometimes angular and grading into sandstone-like material. The rock shows a kind of stratification of fragmental and fine-grained varieties, and this is often nearly horizontal, but at the north end of the pipe at the junction with the hard sandstone belonging to the Red beds there is an inward dip of the tuff. Two other tiny necks lie close at hand—the whole group is located along a line less than a third of a mile in length—both filled with tuff, but in one of these there is a patch of material crowded with spherical lumps of sandstone and impure limestone from the size of a small marble up to that of a golf ball. On the western side of the farm Buffels Fontein there is another group of small necks noticeable inasmuch as they form small knobs rising from a plain of Red beds. An inward dip of the strata around the contacts characterises each of these necks. Basalt fragments occur in portions of the tuffs, while two of the occurrences are almost entirely of basalt probably in the nature of plugs.

A conspicuous little tuff neck is also to be seen on the northern side of the same farm at the foot of the range of hills extending into Frere Dale. Another insignificant example occurs at the southern end of the farm Alleman's Ruigte; the hard grits in contact with the tuff have been much shattered but have since been re-cemented.

The pipe on the north-western boundary of Oorlog's Poort has already been referred to in connection with the sheet of amygdaloidal dolerite which cuts through it. The Red beds have been shattered and indurated around the pipe. The

tuff, except on the northern side wher colour and sandy in character, is pale fragments of sandstone and shale, wl both compact and amygdaloidal basa abundant, are sometimes as much as 1 across.

A similar neck is situated on the sic towards the north but within the farm

A little to the west of this point there a of basalt and breccias, of which some considered as volcanic necks, while the others is rather uncertain.

The first of these is the conspicuous c height of about 500 feet and falling wit Berg; this was mapped by Dunn as a rocks resting upon Red beds. It is reall basalt which fills a pipe about 250 yards in the middle and of which one portion hill. The material is mostly black, con appearance, resembling closely the ensta Pronk's Berg; sometimes it exhibits Along the boundaries of the pipe the a drab colour, is very fine grained and fu so that it is impossible to procure well-sh The surrounding beds are shattered a contacts, and on the eastern side the inwards at a high angle; the pipe is loc a small monoclinal fold striking north other patches of basaltic rock occur close habit. One of these lies just within the l close to the Leeuwe Spruit fence and n to Jamestown. The occurrence forms a in plan and shows fine-grained rock ir indurated (Red beds) sandstone; towarc becomes markedly vesicular passing intc

Just on the other side of the fence ther situated intrusive patches of rock, each wi developed in the interior. A thin secti rock of one of these to be an andesitic-ba of plagioclase and augite set in a colourl specific gravity is 2·825.

The farm Witkop, close to Jamestown, the curious hill of sandy tuff with one which rises to a height of about 450 feet at one point. The rock of which it is co tough and massive; huge blocks which

strew the slopes, some attaining a length of 20 feet. The bulk of the material is a yellowish sandstone, faintly bluish when fresh but brownish when weathered; it is devoid of bedding planes and is eaten into hollows especially where it passes into a true tuff. Such fragmental material is not abundant and is confined mostly to the northern and western edge of the pipe; it is bluish, moderately fine grained and full of small fragments of shale and sometimes larger ones of sandstone, but inclusions of volcanic rock are absent. The tuff is found as vein-like bands between areas of hard sandy material, but grading into the latter with which it must be contemporaneous. The area is about 250 yards in diameter, probably slightly pear-shaped in plan with one dyke-like tongue projecting from the west side.

Less than a mile to the south there rises a nearly similar hill, flatter on the top however and connected with the plateau of Red beds behind; this is also a neck and exhibits some curious features. On the east and south-east there are masses of hard sandstone-like material cutting through the Red beds. Ascending along the north-east there is a large amount of pale tuff full of fragments of sandstone and shale and very uniform in grain. It occurs at the edge of the pipe and at the foot of a cliff of yellow sandstone. Higher up and round to the right this tuff becomes bedded, dipping in at an angle of about 10°, and a good section of the contact is afforded by a small cave. A small pipe occurs nearly midway between the two necks just described; hard tuff cuts through the Red beds in a belt not more than 100 feet wide but traceable for 150 yards down the steep slope. At one point on each side the junction is exposed and the tuff shows a kind of vertical bedding or fluting along which it tends to peel off in slabs.

To the north of Telemachus Kop there are several more of these tuff necks. One conspicuous one forms a nearly white solid dome in the midst of Red shales on a spur of the Stormbergen on the farm Limoen Kloof; it is over 120 yards in diameter. At the northern corner of Zuurbron there are three small necks of this type but which do not call for further description.

*The Telemachus Kop Neck.*—Thirty-five years ago Dunn noticed the curious assemblage of rocks on the eastern slope of Telemachus Kop and interpreted it as the site of a volcanic neck. In this respect he was certainly right, but the ridges round about, which he imagined might represent the rim of the original crater, owe their existence to a later intrusion of olivine-dolerite and the rudely crater-like outline is therefore due to subsequent weathering.

From the map it will be seen that this
from the south-west splits and then reun
of Red beds and the small tract occupied
summit of the hill the dolerite is prisma
arranged in various directions ranging
and the horizontal. While the rock of t
coarse ophitic dolerite, that at the su
finer in grain ; the specific gravity is 2·
slope of the hill there are patches of san
blue-black lavas, sometimes vesicular b
sometimes glassy like the andesites of I
is also a dark blue tuff with red splotches
(2764) under the microscope is seen to
fragments of basalt, and splinters of p
lava. These have been deeply weathere
and pyroxene crystals are represente
and the groundmass by opaque red
however, remain nearly unaltered. The
varies suddenly from point to point as w
case in a pipe of this kind. Dolerit
sandstone, tuff alternate at the foot
are also examples of pitchstone and l
tuff is also found along the junction of th
and the sandstone within the ring. A d
through the dolerite and trends in a
direction towards Limoen Kloof.

One of the thin sections (2765) of an
2·82) shows large serpentinised olivine
fibrous structure, labradorite felspar in la
and having augite moulded upon them,
patchy groundmass is formed of clear br
long fibres of augite strung with tiny c
In one large patch the centre of the area
of the glass into an orange yellow su
double refraction.

Section 2766 is taken from a pitch
probably belong to the group of the an
dark and mottled in appearance and resi
density of only 2·44. It is almost entirel
colourless to faint yellow in section, in
aggregates of felspar, crowds of delicate
with no regular orientation, and a few g

*The Modder Fontein Volcano.* This
on the western side of Telemachus Kop, e
Zuurbron across the full extent of M
although as will be explained in the sequ

sometimes ill-defined, it has a length of not less than three and a half miles from north to south, with an average width of nearly one and a half miles. It covers an area of six square miles and is, therefore, by far the largest volcanic neck that has been discovered in the Cape Province.

All round this pipe the Red beds show an inward dip which varies usually from 3° to 10°, but which sometimes exceeds 20° in value; as the boundary is approached the increase in dip is commonly sudden after which tuff and agglomerate make their appearance. In some places the limit of the neck is pretty sharply defined, as for example on the boundary between Zaai Plaats and Zuurbron, and again immediately to the west of the homestead on Remainder of Modder Fontein. Elsewhere the strata may be found to have been tilted and in some instances fractured while veins of tuff and breccia pass through the disturbed beds. Such is the case on the western slope of Telemachus Kop, where, though it is clear that the broken ground extends further to the east, there appears to be no direct connection with the volcanic neck which was observed on the eastern flank of the hill.

A similar state of affairs exists at the extreme southern end of the neck and two subsidiary areas of tuff and shattered strata have been indicated on the map as distinct pipes. Along the border of Dank Fontein the tuffs end against the sill of dolerite which passes insensibly into vesicular basalt as described earlier in this report. The bulk of the material filling the pipe is a coarse dark green tuff or agglomerate rich in volcanic débris from finely divided basaltic lava up to blocks many feet across and including many varieties. The rock has a purplish tint owing to the abundance of fragments of purple and red shale. It is indeed noticeable how brilliant is the colouring of the inclusions of Red beds everywhere, much more so than in the natural exposures of these strata outside the pipe.

The area occupied by agglomerate is apt to be underestimated, for this rock breaks down readily to form soil, so that one's attention is usually drawn to the yellow or red masses of tilted sandstone projecting above the surface of the grass-covered ground. In many places the tuff shows distinct stratification usually at angles of from 10° to 30°, sometimes very much more, the dip, however, varying rapidly in both amount and direction from point to point. This is only what would be expected in a neck of this size.

On the northern rim of the neck large inclusions of Cave sandstone are seen, at times several hundred feet across, isolated in the tuff and usually disturbed and broken. This rock

is, however, not always recognisable with certainty as the formation is rather thin in the area in question.

On the western side of the neck on Zuurbron (*C*) the Cave sandstone outside the pipe is found resting upon the Red beds and followed by stratified volcanic ash of a red colour. The succession is triplicated in such a way as to show that the strata along the rim have been separated into blocks each a quarter of a mile across by faults transverse to the edge of the volcano ; on the east the strata are cut off by dark greenish agglomerate. At the homestead on Remainder of Modder Fontein there occurs isolated in the agglomerate a huge inclusion half a mile in length in which the strata are dipping uniformly at an angle of 30° in a southerly direction.

This block shows from 50 to 60 feet of Cave sandstone resting upon brilliant red-purple shales and sandstones, followed by 30 feet of coarse red volcanic ash which becomes finer in texture and brighter red in colour at its summit and is succeeded by from 150 to 200 feet of basalts, representing several distinct flows, some of which show bands of pipe-amygdaloid.

This is clearly a huge block, a portion of the crater wall, which has given way and subsided into the neck ; the vertical displacement cannot have been great for the Cave sandstone is found undisturbed outside the pipe half a mile to the west. Between this isolated block and the little hill on which the farm beacon is placed there are great masses of basaltic lavas with bedded volcanic ashes and some thin intercalated bands of yellow sandstone, cleariy huge inclusions of still higher horizons of the volcanic series. There are also bedded vesicular green lavas and green tuffs cut by nearly vertical narrow but irregular dykes of yellow and pinkish sandy rock. At this point the inclusions of red and purple shale and sandstone are of surprisingly brilliant colouring while lavas of all types are represented varying in colour from black to green and purple and from compact to highly vesicular varieties ; pipe-amygdaloid is of constant occurrence.

Some of the larger inclusions attain a length of 15 feet, but it is sometimes uncertain whether some of the more extensive exposures of compact basalt are not dyke-like in habit, for small intrusions of this nature are not uncommon within the pipe and are especially numerous towards the Dank Fontein boundary.

The Modder Fontein Volcano doubtless came into existence while the Cave sandstone was being laid down, for in an outlier of the latter on the boundary with Vaalbank the sandstone is full of small fragments of shale and sandstone. From

this pipe also there must have been ejected the material which composes the ash-bed on Dank Fontein.

The enlargement of the pipe probably caused subsidence of the strata adjoining and large portions including masses of bedded basaltic lavas broke away from the sides to become engulfed in the agglomerate. The downward drag nea the edge was no doubt responsible for the fracture in the strata which encircles the volcano and along which molten rock rose which solidified to form the ring-shaped outcrop of dolerite now surrounding the neck. Along its entire length, as has been pointed out already, the dip of the intrusion is inwards towards the pipe and the distance of the outcrop from the edge of the latter is never more than a mile. The evidence indicates also that the dolerite rose in this fracture during the life of the volcano, possibly when the neck was temporarily choked with débris, and seems to have poured out sub-aerially in the region immediately to the south of this centre of eruption.

At a much later period there burst through the agglomerate, basalts and dolerite alike the long narrow dyke of dolerite shown on the map running in a south-south-easterly direction and cutting across the eastern part of the vent.

### *The Fractured Areas on Frère Dale and Lemoen Fontein.*

A puzzling piece of country as regards the position of the Cave sandstone is found on the farm Frere Dale. To the west of the main road to Molteno the tops of the hills, here from 600-800 feet in height, are crowned by outliers of Cave sandstone; eastwards the Red beds are flexed upwards and lower and lower strata appear in that direction, the dip being over 30° finally. Then immediately to the east of the road this basal part of the Red beds is found in contact with Cave sandstone, the latter forming a cliff a few hundreds of feet in height, curving away to the north-east and to the south-east at its extremities. At the small gorge where the road from the Frere Dale homestead ascends the plateau the junction of the two formations which are dipping away from each other is found to be a fault. At the back of this cliff-like edge the geology becomes more complex; the Red beds are bleached, they are tilted now this way, now that way, and there are some large inclined sheets of dolerite.

One of these forms the ridge on which the northern-most beacon of Buffel's Fontein stands. It is a tough rock with peculiar leaden-grey or brown-grey exterior breaking along joints and giving a jagged fracture; it is fine grained and like a basalt in texture.

A rock of this type, part of the same intrusion in fact, is found on the dome-shaped hill to the north, from which rises the line beacon between Frere Dale and Kalkoen Kranz. The thin section (2776) shows several large crystals composed of chlorite and quartz and probably originally of felspar; these are moulded upon and include prisms of labradorite felspar and patches of glass. Labradorite felspar is abundant in very clear fresh prisms set in a dark translucent matrix, which under a high magnification is found to consist of crowds of excessively minute augite granules along with glass, iron ores, etc. The specific gravity is 2·78.

It is in close association with coarsely ophitic dolerite as at Zuurbron and breaks through the strata tilting the latter to angles to 30°. Descending into Kalkoen Kranz towards the homestead the beds are found to be broken and to be penetrated by small masses of basalt accompanied by greenish volcanic tuff and agglomerate here and there.

There is no doubt that this tract marks an area of volcanic eruption followed by subsidence; possibly the strata were first bent into a dome which then collapsed, the Cave sandstone breaking off along a fault line, falling inwards and then being penetrated by volcanic rocks and breccias.

The peculiarly disturbed area on Stafelberg's Vley immediately to the north of the Sterkstroom-Indwe railway was briefly described in the Annual Report for 1905 (p. 130). This season's work shows that the disturbance continues several miles to the northward into the farm Lemoen Fontein, while a second region of tilted strata lies a little distance to the west on the farm Drooge Fontein.

It will be recalled that steeply dipping beds were found on Stafelberg's Vley enveloped in dolerite and displaced considerably in position. North of the eastern beacon of th farm the strata are however found dipping in a very regul manner at angles of from 30° to 40° towards the north-w as shown in Fig. 2.

At the head of the valley the pebbly sandstones o Molteno beds, here brought up a distance of nearly 1,o above their normal position, are found making cons ridges, each sandstone being accompanied by a dolerite intruded along the bedding planes.

They are followed in turn by the Red beds wit directed dip, but the inclination diminishes and fin when the nearly vertical ring-shaped dolerite dyk at the homestead on Boshoff's Kraal, this intr the limit of the disturbed ground and occurri of fault with upthrow to the south. It c

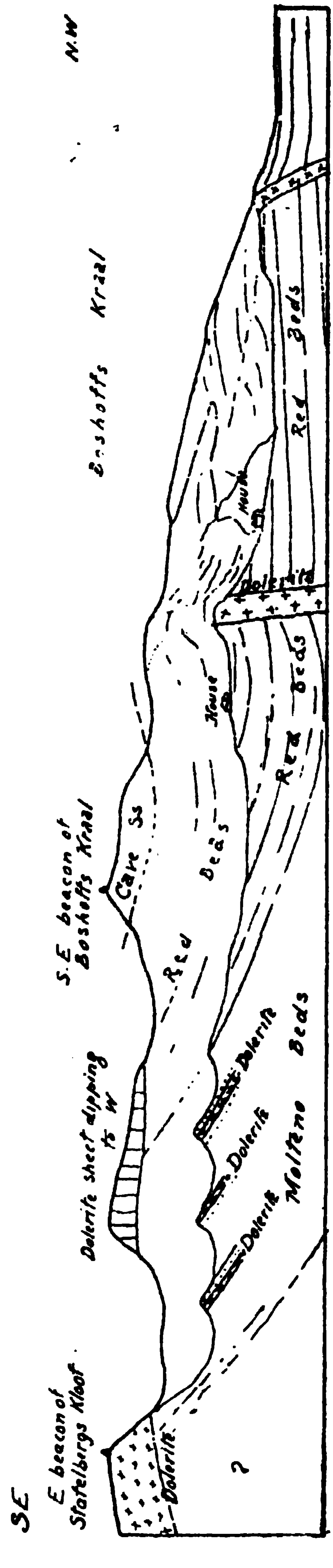



FIG. 2.—Diagrammatic section along valley descending from Stafelberg's Kloof to Boshoff's Kraal showing also the higher ground to the south-west. Length of section about 4 miles.

either end and merges in the great dolerite mass which determines the watershed of the district forming rounded and dome-shaped hills; at the south-easterly beacon of Boshoff's Kraal the Cave sandstone appears in its normal position.

Within the farm Wagen Pads Kloof, close at hand, there occurs in the dolerite just below the summit of the ridge a strip of indurated sandstone accompanied by a thick and extensive bed of volcanic ash. The latter is reddish to greenish in colour with small inclusions only and shows faint stratification. In its central portion the rock is coarser in texture and better bedded. Below it there comes dolerite again, and from the fact that the ash is indurated at both upper and lower contacts and is cut by dolerite in places it seems as if the material is merely a huge inclusion of volcanic ash a couple of hundred feet in thickness and about a mile in length torn off from the Cave sandstone and isolated in the igneous rock. At the north-easterly beacon of this farm the dolerite is an unusual fine-grained variety rich in quartz (quartz-dolerite), while below it on the north side there are thin strips of highly altered ashes.

## THE DOLERITES.

The dolerites of this area occur generally in the form of either inclined sheets or narrow vertical dykes; horizontal sheets are unrepresented.

The inclined sheets give rise to serrated chains of hills usually unsymmetrical in appearance, while in plan they tend to be arranged in curves having greater or less regularity.

On Middel Plaats a sheet, probably from 100 to 200 feet in thickness, dips in below the centre of the farm at angles of from 15° to 40° and gives rise to a ring-shaped outcrop about four miles across; it is an extremely good example of one of the basin-shaped intrusions so well known in the region further to the south. The sheet rises up to cut through and to spread out in the Cave sandstone at the summit of Middel Plaats Berg, where it is finely columnar in habit. The rock is a coarse-grained ophitic olivine-dolerite of specific gravity 2·95, the average density of the intrusions of this nature in this district. On the south-east this ring is joined to an intrusion of similar habit enclosing within an oval area six miles in length the greater part of the farms Sneyman's Kraal and Vogel Vley. The ring is not quite complete on its eastern side, for at the Toren Berg through a distance of a few miles the dip is eastwards instead of westwards due to an interfering sheet which forms a most irregular outcrop in its course from Oorlog's Poort to Palmiet Fontein and to which attention has already been drawn.

Some of these inclined sheets gradually become steeper and are finally continued as vertical dykes, but this is not very common. An example of a composite sheet was noticed on the farm Oorlog's Poort on the face of the hill overlooking the homestead. A second and thicker intrusion has been injected below a sheet of coarse-grained dolerite. The later rock, which is coarse in character in the middle and at the base, becomes finer grained as the contact is approached, while a columnar structure has been developed in the uppermost part of the intrusion. Of still greater interest is the occurrence of several younger dykes cutting both of these sheets. One of these goes straight up the hill side giving a very clear section; it is from 6 to 12 feet in width and runs from Leeuw Fontein in the south to beyond Swak Fontein in the north. Another dyke strikes nearly at right angles to this but is only from three to four feet broad. It is accompanied by a narrow and almost parallel intrusion which maintains for a distance of several hundred feet in the dolerite sheet the following double

character, namely, two dykes each seven inches broad parted by three inches of dolerite. The dyke material is very fine grained and breaks into rough prisms crossing horizontally from side to side.

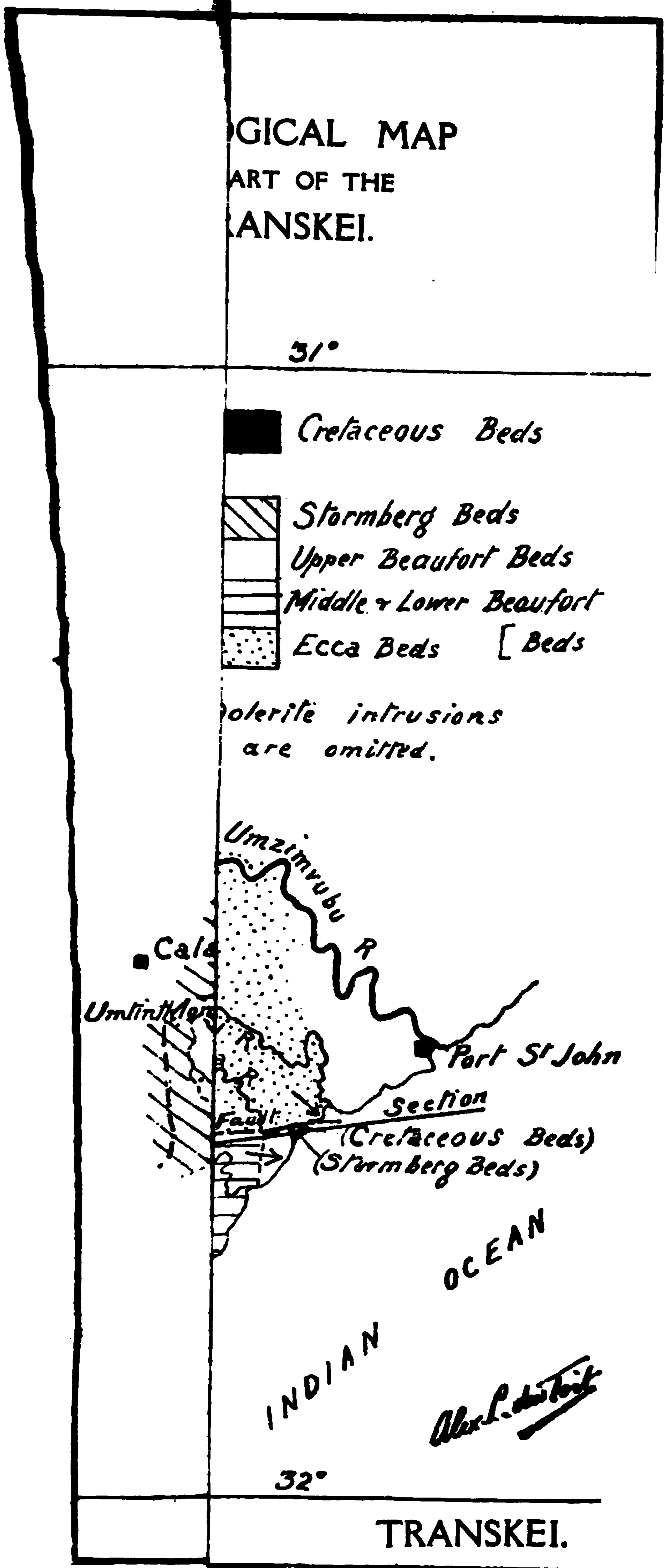
Of the narrow dykes in this area a large proportion trend in a north-north-westerly direction and are crossed roughly at right angles by a complimentary set. Some of these dykes are of considerable length, in which case the intrusion is younger than the dolerite sheets as a rule.

An excellent example is the dyke crossing the Modder Fontein volcano; commencing in the Stormbergen, it crosses Uitkyk, Pronk's Kraal, and Vogel Vley, being finally lost in the dolerite ridges above Birds' River Siding, a distance of 32 miles. Another dyke crosses this one obliquely cutting through Toren Berg and continuing outside the area beyond Wolve Fontein. Of east-west dykes the best example is one which crosses Klip Fontein and Lelie Kloof, cutting through the volcanic rocks.

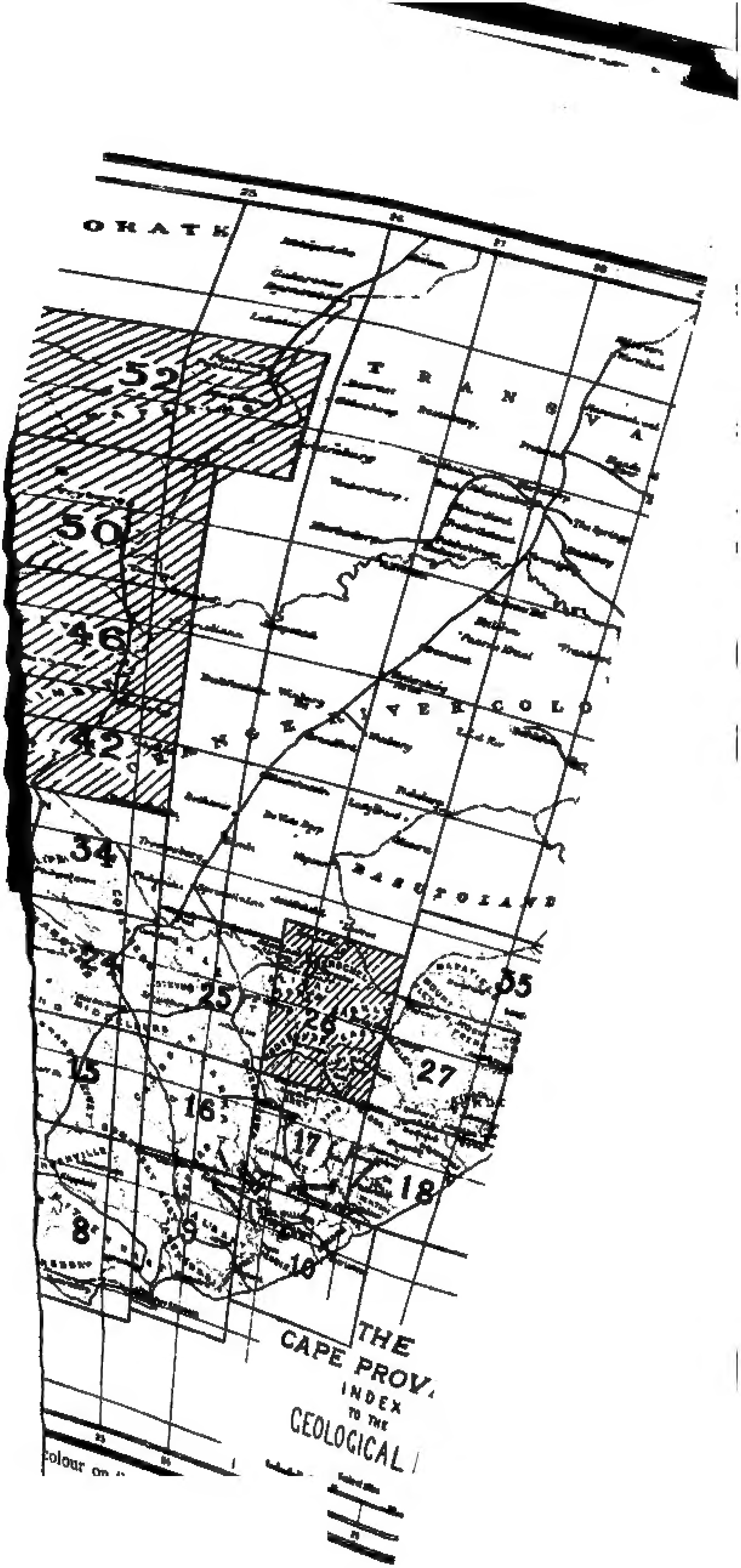
The relationship of the dolerites to the basalts has already been discussed, so that there is no necessity of enlarging on this subject.

# INDEX.

34



GICAL MAP
ART OF THE
ANSKEI.
31°
Cretaceous Beds
Stormberg Beds
Upper Beaufort Beds
Middle & Lower Beaufort Beds
Ecca Beds
olerite intrusions are omitted.
Umzimvubu R.
Port St John
Section
Fault
(Cretaceous Beds)
(Stormberg Beds)
INDIAN OCEAN
Alex L. du Toit
32°
TRANSKEI.


52
50
46
42
34
24
25
26
35
27
15
16
17
18
8
9
10
THE
INDEX
TO THE